AD-784 188

DEVELOPMENT OF ACCELERATED LIFE TESTING TECHNIQUES FOR GENERAL FAILURE MODES OF AIRCRAFT HARDWARE

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Prepared for:

Army Air Mobility Research and Development Laboratory

May 1974

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A three-dimensional, failure-experience, cell matrix was developed to categorize the generic failure mode, elemental mechanical function, and corrective action data from more than 500 historical Army helicopter hardware problems. The matrix may be developed for use as a design tool to aid in the prediction and prevention of potential mechanical failures at the component design stage, and as a library of successful corrective actions for use by project managers and design engineers in solving problems that occur in operational equipment.

The conclusions and recommendations contained herein are concurred in by this Directorate. The methodology contained herein will be useful in reducing the frequency and severity of future mechanical problems.

The technical monitor for this contract was Mr. Gary R. Newport, Military Operations Technology Division, Eustis Directorate.

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AD-784188

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER USAAMRDL-TR-74-36	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) DEVELOPMENT OF ACCELERATED LIFE TESTING TECHNIQUES FOR GENERAL FAILURE MODES OF AIRCRAFT HARDWARE		5. TYPE OF REPORT & PERIOD COVERED Final Report 1 Jan through 31 Dec 1973
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Jack A. Collins Ben Tarver Hagan, Jr.		8. CONTRACT OR GRANT NUMBER(s) Contract DAAJ02-73-C-0023
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Mechanical Engineering The Ohio State University Research Foundation Columbus, Ohio 43210		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Task 1F162203A11907
11. CONTROLLING OFFICE NAME AND ADDRESS Eustis Directorate U. S. Army Air Mobility R&D Laboratory Fort Eustis, Virginia 23604		12. REPORT DATE May 1974
		13. NUMBER OF PAGES 330
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Accelerated testing	Life
Mechanical properties	Predictions
Failure	Wear
Helicopters	Correctives

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objective of the investigation was to determine the feasibility of developing reliable accelerated life testing methods for aircraft hardware, based on currently documented failure case histories. Over 240 case histories involving more than 500 individual parts were categorized according to failure mode, elemental mechanical function, and corrective action employed. A three-dimensional failure-experience cell matrix was

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. Continued.

developed to implement the organization and analysis of the data. Efforts to quantitatively evaluate corrective action effectiveness were frustrated by a lack of quantitative data, but a qualitative evaluation was accomplished.

Wear was identified as the most frequently occurring failure mode in the cases studied, accounting for nearly half of all failures. The feasibility of developing an accelerated life wear testing procedure was investigated and found to have the potential for further investigation. It is thought that experimental development of the accelerated wear testing technique has the potential for providing a significant advance in wear life prediction.

The failure-experience matrix developed in the investigation proved to be an extremely useful tool in organizing and analyzing the documented failure data. The failure-experience matrix might also prove to be an important design tool, useful in improving the prediction and prevention of potential mechanical failure at the design stage.

PREFACE

This investigation was conducted under Contract DAAJ02-73-C-0023 (DA Task 1F162203A119-07) administered by Eustis Directorate of the U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia. The contracting officer's technical representative monitoring this contract was Mr. Gary Newport. The authors wish to express appreciation to Mr. Gary Newport and Mr. Howard Bratt of the Eustis Directorate for providing essential information and documentation throughout the contract period. Appreciation is also expressed for courtesies shown the authors during their visit to U. S. Army Aeronautical Depot Maintenance Center (USAARADMAC) facilities at Corpus Christi, Texas, by Mr. Newman P. Bulloch, and for the cooperation of Messrs. Dick Bee, Tom Tullos, Stig Boberg, Bob Ladner, and W. H. Roberts.

Supporting efforts by Ohio State University graduate students Max Herschler, Harvey Lyons, Ginn Lee, Glenn Steyer, and Imtiyaz Syed are recognized.

The period of time covered by this investigation was from January 1, 1973, through December 31, 1973.

TABLE OF CONTENTS

	Page
PREFACE	iii
LIST OF ILLUSTRATIONS	vii
LIST OF TABLES	xv
INTRODUCTION	1
DEVELOPMENT OF A FAILURE-EXPERIENCE MATRIX FOR ORGANIZATION OF FAILURE DATA	3
Failure Modes	4
Elemental Mechanical Functions	5
Corrective Actions	10
REVIEW AND ORGANIZATION OF FAILURE CASE HISTORY DATA FOR INSERTION INTO FAILURE-EXPERIENCE MATRIX	13
Failure Mode Assessment	13
Elemental Mechanical Function Classification	14
Corrective Action Determination	15
Compilation of Data	16
ANALYSIS OF FAILURE-EXPERIENCE MATRIX	17
Overall Analysis of Results	17
Analysis of Data for which the Corrective Actions Resulted in an Improvement	30
Analysis of Data for which the Corrective Actions Resulted in No Improvement	40
DEVELOPMENT OF ACCELERATED TESTING PROCEDURE FOR PREDICTION OF FAILURE BY WEAR	44
Wear Models and Testing Methods	45
Specimen Selection	47
Selection of Accelerated Stressor Ranges	47
Definition of Failure by Wear in the Cyclic Servo Support Bearing	48
Testing Machine Requirements	49
Definition of an Accelerated Wear Testing Program	49

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TABLE OF CONTENTS - Continued

	Page
SUMMARY AND CONCLUSIONS	53
REFERENCES	191
APPENDIXES	
I. Glossary for Failure Modes	192
II. Glossary for Elemental Mechanical Functions	197
III. Glossary for Corrective Actions	201
IV. Basic Information Stored in Failure-Experience Matrix	204
LIST OF SYMBOLS	312

LIST OF ILLUSTRATIONS

Figure		Page
1	Illustration of a Portion of the Failure-Experience Matrix Used to Evaluate Documented Mechanical Failure Problems in U. S. Army Helicopters	55
2	Frequency of Corrective Action Usage for Elastic Deformation Failure Mode - Series I	56
3	Frequency of Corrective Action Usage for Yielding Failure Mode - Series I	57
4	Frequency of Corrective Action Usage for Ductile Rupture Failure Mode - Series I	58
5	Frequency of Corrective Action Usage for Brittle Fracture Failure Mode - Series I	59
6	Frequency of Corrective Action Usage for Fatigue Failure Mode - Series I	60
7	Frequency of Corrective Action Usage for Surface Fatigue Failure Mode - Series I	61
8	Frequency of Corrective Action Usage for Impact Failure Mode - Series I	62
9	Frequency of Corrective Action Usage for Wear Failure Mode - Series I	63
10	Frequency of Corrective Action Usage for Corrosion Failure Mode - Series I	64
11	Frequency of Corrective Action Usage for Brinelling Failure Mode - Series I	65
12	Frequency of Corrective Action Usage for Galling Failure Mode - Series I	66
13	Frequency of Corrective Action Usage for Creep Failure Mode - Series I	67
14	Frequency of Corrective Action Usage for Stress Rupture Failure Mode - Series I	68
15	Frequency of Corrective Action Usage for Fretting-Corrosion Failure Mode - Series I	69

LIST OF ILLUSTRATIONS - Continued

Figure		Page
16	Frequency of Corrective Action Usage for Fretting-Wear Failure Mode - Series I	70
17	Frequency of Corrective Action Usage for Fretting-Fatigue Failure Mode - Series I	71
18	Frequency of Corrective Action Usage for Corrosion-Fatigue Failure Mode - Series I	72
19	Frequency of Corrective Action Usage for Impact-Fatigue Failure Mode - Series I	73
20	Frequency of Corrective Action Usage for Buckling Failure Mode - Series I	74
21	Frequency of Corrective Action Usage for Change in Material Properties Failure Mode - Series I	75
22	Frequency of Corrective Action Usage for Leakage Failure Mode - Series I	76
23	Frequency of Corrective Action Usage for Scoring Failure Mode - Series I	77
24	Frequency of Corrective Action Usage for Delamination Failure Mode - Series I	78
25	Frequency of Corrective Action Usage for Bonding-Failure Failure Mode - Series I	79
26	Frequency of Corrective Action Usage for Erosion Failure Mode - Series I	80
27	Frequency of Corrective Action Usage for Lubrication-Failure Failure Mode - Series I	81
28	Frequency of Corrective Action Usage for Imbalance Failure Mode - Series I	82
29	Frequency of Corrective Action Usage for Electrochemical Overheating Failure Mode - Series I	83
30	Frequency of Corrective Action Usage for Seizure Failure Mode - Series I	84

Figure		Page
31	Frequency of Corrective Action Usage for Clogged Filter Failure Mode - Series I	85
32	Frequency of Corrective Action Usage for Electrical Failure Mode - Series I	86
33	Frequency of Corrective Action Usage for Improper Dimension Failure Mode - Series I	87
34	Frequency of Impaired Elemental Functions for the Improved Part Corrective Action - Series II	88
35	Frequency of Impaired Elemental Functions for the Direct Replacement Corrective Action - Series II	90
36	Frequency of Impaired Elemental Functions for the Change of Material Corrective Action - Series II	92
37	Frequency of Impaired Elemental Functions for the Supplemental Part Corrective Action - Series II	94
38	Frequency of Impaired Elemental Functions for the Improved Instructions to Field Personnel Corrective Action - Series II	96
39	Frequency of Impaired Elemental Functions for the Changed Dimensions Corrective Action - Series II	98
40	Frequency of Impaired Elemental Functions for the Changed Loading on Part Corrective Action - Series II ...	100
41	Frequency of Impaired Elemental Functions for the Applied Surface Coating Corrective Action - Series II ...	102
42	Frequency of Impaired Elemental Functions for the Changed Mechanism of Operation Corrective Action - Series II	104
43	Frequency of Impaired Elemental Functions for the Relocated or Repositioned Part Corrective Action - Series II	106
44	Frequency of Impaired Elemental Functions for the Repaired Corrective Action - Series II	108

LIST OF ILLUSTRATIONS - Continued

Figure Page

45 Frequency of Impaired Elemental Functions for the Changed Method of Attachment Corrective Action - Series II 110

46 Frequency of Impaired Elemental Functions for the Changed Manufacturing Procedure Corrective Action - Series II 112

47 Frequency of Impaired Elemental Functions for the Reinforced Part Corrective Action - Series II 114

48 Frequency of Impaired Elemental Functions for the Eliminated Part Corrective Action - Series II 116

49 Frequency of Impaired Elemental Functions for the Strengthened Part Corrective Action - Series II 118

50 Frequency of Impaired Elemental Functions for the Changed Method/Frequency of Lubrication Corrective Action - Series II 120

51 Frequency of Impaired Elemental Functions for the Changed Vendor Corrective Action - Series II 122

52 Frequency of Impaired Elemental Functions for the Added or Changed Adhesive Material Corrective Action - Series II 124

53 Frequency of Impaired Elemental Functions for the Improved Quality Control Corrective Action - Series II .. 126

54 Frequency of Impaired Elemental Functions for the Changed Type or Added Lubricant Corrective Action - Series II 128

55 Frequency of Impaired Elemental Functions for the Improved Run-In Procedure Corrective Action - Series II 130

56 Frequency of Impaired Elemental Functions for the Applied Surface Treatment Corrective Action - Series II 132

Figure		Page
57	Frequency of Impaired Elemental Functions for the Added Sealant Corrective Action - Series II	134
58	Frequency of Impaired Elemental Functions for the Added or Changed Locking Feature Corrective Action - Series II	136
59	Frequency of Impaired Elemental Functions for the Adjusted Part Corrective Action - Series II	138
60	Frequency of Impaired Elemental Functions for the Provided Drain Corrective Action - Series II	140
61	Frequency of Impaired Elemental Functions for the More Easily Replaceable Corrective Action - Series II	142
62	Frequency of Impaired Elemental Functions for the Changed to Correct Part Corrective Action - Series II	144
63	Frequency of Impaired Elemental Functions for the Improved Lubrication Corrective Action - Series II	146
64	Frequency of Impaired Elemental Functions for the Made Parts Interchangeable Corrective Action - Series II	148
65	Frequency of Impaired Elemental Functions for the Relaxed Replacement Criteria Corrective Action - Series II	150
66	Frequency of Impaired Elemental Functions for the Provided Means for Proper Inspection Corrective Action - Series II	152
67	Frequency of Impaired Elemental Functions for the Changed Electrical Characteristics Corrective Action - Series II	154
68	Frequency of Occurrence of Failure Modes for Improved Part Corrective Action - Series III	156
69	Frequency of Occurrence of Failure Modes for Direct Replacement Corrective Action - Series III	157

LIST OF ILLUSTRATIONS - Continued

Figure		Page
70	Frequency of Occurrence of Failure Modes for Change of Material Corrective Action - Series III	158
71	Frequency of Occurrence of Failure Modes for Supplemental Part Corrective Action - Series III	159
72	Frequency of Occurrence of Failure Modes for Improved Instructions to Field Personnel Corrective Action - Series III	160
73	Frequency of Occurrence of Failure Modes for Changed Dimensions Corrective Action - Series III	161
74	Frequency of Occurrence of Failure Modes for Changed Loading on Part Corrective Action - Series III	162
75	Frequency of Occurrence of Failure Modes for Applied Surface Coating Corrective Action - Series III	163
76	Frequency of Occurrence of Failure Modes for Changed Mechanism of Operation Corrective Action - Series III	164
77	Frequency of Occurrence of Failure Modes for Relocated or Repositioned Part Corrective Action - Series III	165
78	Frequency of Occurrence of Failure Modes for Repaired Corrective Action - Series III	166
79	Frequency of Occurrence of Failure Modes for Changed Method of Attachment Corrective Action - Series III	167
80	Frequency of Occurrence of Failure Modes for Changed Manufacturing Procedure Corrective Action - Series III	168
81	Frequency of Occurrence of Failure Modes for Reinforced Part Corrective Action - Series III	169
82	Frequency of Occurrence of Failure Modes for Eliminated Part Corrective Action - Series III	170

LIST OF ILLUSTRATIONS - Continued

Figure		Page
83	Frequency of Occurrence of Failure Modes for Strengthened Part Corrective Action - Series III	171
84	Frequency of Occurrence of Failure Modes for Changed Method or Frequency of Lubrication Corrective Action - Series III	172
85	Frequency of Occurrence of Failure Modes for Changed Vendor Corrective Action - Series III	173
86	Frequency of Occurrence of Failure Modes for Changed Adhesive Material Corrective Action - Series III	174
87	Frequency of Occurrence of Failure Modes for Improved Quality Control Corrective Action - Series III	175
88	Frequency of Occurrence of Failure Modes for Changed Type or Added Lubricant Corrective Action - Series III	176
89	Frequency of Occurrence of Failure Modes for Improved Run-In Procedure Corrective Action - Series III	177
90	Frequency of Occurrence of Failure Modes for Applied Surface Treatment Corrective Action - Series III	178
91	Frequency of Occurrence of Failure Modes for Added Sealant Corrective Action - Series III	179
92	Frequency of Occurrence of Failure Modes for Added or Changed Locking Feature Corrective Action - Series III	180
93	Frequency of Occurrence of Failure Modes for Adjusted Part Corrective Action - Series III	181
94	Frequency of Occurrence of Failure Modes for Provided Drain Corrective Action - Series III	182
95	Frequency of Occurrence of Failure Modes for More Easily Replaceable Corrective Action - Series III	183

LIST OF ILLUSTRATIONS - Continued

Figure		Page
96	Frequency of Occurrence of Failure Modes for Changed to Correct Part Corrective Action - Series III	184
97	Frequency of Occurrence of Failure Modes for Improved Lubrication Corrective Action - Series III	185
98	Frequency of Occurrence of Failure Modes for Made Parts Interchangeable Corrective Action - Series III	186
99	Frequency of Occurrence of Failure Modes for Relaxed Replacement Criteria Corrective Action - Series III	187
100	Frequency of Occurrence of Failure Modes for Revised Procurement Specifications Corrective Action - Series III	188
101	Frequency of Occurrence of Failure Modes for Provided Means for Proper Inspection Corrective Action - Series III	189
102	Example of Accelerated Life Testing Using the Linear Cumulative Damage Model	190
103	Schematic View of Cyclic Servo Support Bearing	190

LIST OF TABLES

Table		Page
I	Failure Modes Included in the Failure-Experience Matrix	4
II	List of Key Words Used in Defining Elemental Mechanical Functions	6
III	Auxiliary List of Antecedent Adjectives Used in Defining Elemental Mechanical Functions	7
IV	Elemental Mechanical Functions Included in the Failure-Experience Matrix	7
V	Corrective Actions Included in the Failure-Experience Matrix	11
VI	Corrective Actions Which Were Used at Least Ten Times for a Specified Failure Mode	18
VII	Elemental Mechanical Functions for Which Failure Was Addressed at Least Ten Times by Use of a Specified Corrective Action	21
VIII	Failure Modes Which Were Addressed at Least Ten Times by Use of a Specified Corrective Action	24
IX	Information Cells in the Failure-Experience Matrix Which Contain Eight or More Cases	26
X	Corrective Actions Which Improved Failure Resistance of Certain Elemental Mechanical Functions for Each Observed Failure Mode	31
XI	Corrective Actions Which Resulted in at Least Two Cases With No Improvement in Failure Resistance Associated With Specified Failure Mode	41
XII	Accelerated Wear Testing Program Using Operational Load Amplitude as the Stressor	50
XIII	Accelerated Wear Testing Program Using Operation Frequency of Angular Motion as the Stressor	51
XIV	Information for Each Part Contained in the Failure-Experience Matrix	204

LIST OF TABLES - Continued

Table		Page
XV	Section Through Failure-Experience Matrix Revealing Identification of Case Histories for Which the "Change of Material" Corrective Action Was Proposed	292

INTRODUCTION

The primary objective of the investigation described in this report was to determine the feasibility of developing reliable accelerated life testing methods for aircraft hardware based on currently documented failure case histories. An important part of the investigation was a study of the documented effectiveness of corrective actions proposed and used to reduce or eliminate failures in U.S. Army helicopter subsystems and components. Approximately 240 failure case history packets, together with supplemental drawings and reports, were supplied by Eustis Directorate early in the investigation. All of this information was carefully studied and categorized with respect to failure mode, elemental mechanical function, and corrective action employed for each of the more than 500 individual parts involved in the 240 failure case history packets. This categorization process was carried forth in a completely general way by avoiding the restrictions commonly imposed when failure data are grouped according to specific aircraft model, particular subsystem or individual part.

To implement and systematize the data with respect to failure mode, elemental mechanical function, and corrective action, a three-dimensional cell matrix was developed, as illustrated in Figure 1, with a failure-mode axis, an elemental-mechanical-function axis, and a corrective-action axis. The study identified approximately 40 failure modes, 105 elemental mechanical functions, and 35 corrective actions, so the cell matrix contained a total of approximately 147,000 cells. However, for the failure cases studied the matrix was sparsely populated, with over 90% of the cells empty. Nevertheless, there were approximately 7,500 populated cells and the management and analysis of these data were major tasks.

At the outset of the study, it was hoped that a quantitative figure of merit could be established for many of the corrective actions, if not most of them, to systematically judge the effectiveness of the various solutions contained in a given cell-column of the matrix. The hope for this possibility rested upon the storage of documented field failure information and engineering corrective action effectiveness in computerized central data storage banks. From the outset it was also known that such information might not be plentiful. As the study progressed, it became clear that quantitative information included in the case history packets was extremely sparse; in fact, even qualitative information was often unavailable. Attempts made to procure additional supporting documents met with mixed results. While Eustis Directorate was able to supply many requested documents, a large number were unavailable. To help evaluate the failure problems, a shipment of failed parts from the USAARADMAC Depot in Corpus Christi, Texas, was supplied for inspection. Following this, a visit was made to the USAARADMAC facility for further discussions and information-gathering.

In spite of all efforts to gather data for quantitative evaluation of the effectiveness of corrective actions, it was not possible to obtain enough information to develop a quantitative figure of merit evaluation system.

As may be observed in the results presented, it was necessary to settle for a qualitative evaluation of corrective action effectiveness, and in many cases the effectiveness was unknown. Nevertheless, the results provide some extremely useful insights and form the basis and direction for improving failure prevention effectiveness in the long term. For example, the most frequently occurring failure modes were identified, the most widely used corrective actions for each important failure mode were established, and the effectiveness of these corrective actions was tabulated wherever the information was available. The large category of "unknown" corrective action effectiveness would seem to indicate a need for better documentation of mechanical failure histories, including identification of the basic failure mode, engineering evaluation of the problem, and corrective action proposed, when and how the corrective actions were implemented, and, especially, quantitative results of the corrective action in terms of failure statistics following implementation of the action.

From the survey of failure mode frequency it was determined that wear and wear-related failures, such as fretting-wear, constitute nearly half of all failures among the more than 500 individual failed parts included in this study. Thus, wear was selected as the failure mode for which an accelerated life testing technique would be developed. In spite of the first rank importance of wear as a failure mode, a study of the literature indicated that very little published engineering effort has been directed toward the study of accelerated wear or fretting-wear testing. It was reasoned, therefore, that the development of an accelerated wear testing technique as a tool for wear prediction might provide the highest probability for a significant advance in the state of the art of failure prevention. To this end, several concepts from the research literature were combined to propose an accelerated testing technique for the prediction of long-term wear in a test of short duration. Experimental verification of the proposed accelerated wear life testing technique remains to be accomplished in a future program.

DEVELOPMENT OF A FAILURE-EXPERIENCE MATRIX FOR ORGANIZATION OF FAILURE DATA

To facilitate the organization, management and analysis of the voluminous data and information associated with over 500 individual failed parts, a three-dimensional cell matrix was devised. As depicted in Figure 1, failure modes were plotted along one axis, elemental mechanical functions were located along a second axis, and corrective actions represented by the third axis. Thus a spatial cell was formed at the intersection of any given combination of failure mode, elemental mechanical function and corrective action. Each failed part was classified by failure mode, elemental function and corrective action, and placed into the appropriate cell. When the classifications were complete, it was noted that some cells were heavily populated and many cells were completely empty. Approximately 5 percent of the 147,000 cells contained one or more entries, and the most heavily populated cells contained approximately 37 entries.

Analyses of the data were greatly facilitated by the failure-experience cell matrix approach. For example, it was easily possible to examine frequency of usage of all corrective actions addressed to any given failure mode, frequency of occurrence of impaired mechanical functions to which any given corrective action was applied, or frequency of occurrence of failure modes associated with each corrective action. In addition, the matrix compilation made it possible to aggregate all functions impaired by a given failure mode which were corrected by the same corrective action. All of these correlations and analyses are described in more detail in a later section of this report.

Perhaps the greatest importance of the failure-experience matrix developed here is its potential use as an engineering design and development tool. An engineer faced with the design of a critical component would only need to classify the intended function of his component, enter the matrix with the function, and note the failure modes most likely to occur and corrective actions most likely to avert the failure. Likewise, a development engineer faced with a field failure would only need to identify the active failure mode and classify the function of the part to enter the matrix and read out the corrective action most likely to solve the problem.

By no means does the failure-experience matrix defined by this study contain enough information to solve all design problems. The experience cells are sparsely populated, and quantitative data on effectiveness of corrective actions is incomplete. However, the matrix, as presented, does form a sound basis for cataloging failure experience, not only from helicopters but from throughout all industry, in a way that it would be of direct use to a designer in solving a particular failure analysis problem in a specific part or component. The ultimate usefulness of the failure-experience matrix will depend on the success of future efforts to expand its population and better define the corrective action effectiveness in each cell by a quantitative figure of merit.

The 40 failure modes, 105 elemental mechanical functions, and 35 corrective actions used in the failure-experience matrix are described below. While it is possible that certain isolated mechanical failure problems might require additions to the matrix presented, it is thought that most problems, now and in the future, can be successfully housed in the failure-experience matrix as it stands.

FAILURE MODES

Based on a study of classical mechanical failure modes and close scrutiny of the more than 500 individual part failures associated with the current investigation, Table I has been compiled to show the 40 failure modes used in the failure-experience matrix. The failure modes are listed in order of frequency of occurrence in the current study.

TABLE I. FAILURE MODES INCLUDED IN THE FAILURE-EXPERIENCE MATRIX

Rank	Failure Mode	No. of Occurrences
1	Wear	176
2	Ductile Rupture	160
3	Fatigue	139
4	Leakage	101
5	Yielding	73
6	Impact	68
7	Corrosion	56
8	Bonding Failure	39
9	Seizure	28
10	Surface Fatigue	22
11	Galling	21
12	Scoring	19
13	Change in Material Property	14
14	Erosion	12

TABLE I - Continued		
Rank	Failure Mode	No. of Occurrences
15	Fretting-Fatigue	9
	Elastic Deformation	9
16	Imbalance	8
17	Fretting-Corrosion	7
18	Brittle Fracture	6
	Stress Rupture	6
	Fretting-Wear	6
19	Lubrication Failure	5
	Improper Dimension	5
20	Delamination	4
21	Buckling	3
	Impact-Fatigue	3
	Clogged Filter	3
	Electrical	3
22	Creep	2
23	Brinelling	1
	Corrosion-Fatigue	1
	Electrochemical Overheating	1
24	Radiation Damage	0
	Thermal Relaxation	0
	Thermal Shock	0
	Combined Creep and Fatigue	0
	Stress Corrosion	0
	Corrosion Wear	0
	Spalling	0
	Creep Buckling	0

It may be noted that 32 of the 40 failure modes were observed at least once in this investigation, and wear was observed as a failure mode in 176 cases. A glossary of failure modes is included as Appendix I of this report.

ELEMENTAL MECHANICAL FUNCTIONS

Simple, complete, concise definition of the elemental mechanical function

of each part and component considered in this investigation presented a major challenge. Several different classification procedures were formulated and applied to the failure case histories available. Based on this experience, the method finally selected to define the elemental mechanical function embodied a list of 46 key words and an auxiliary list of 40 antecedent adjectives. In many cases the elemental mechanical function can be described by the selection of a single key word. In other cases an appropriate antecedent adjective must be coupled with a key word to provide an acceptable description of the function. The key word list is given in Table II, and the antecedent adjective list is given in Table III .

Using appropriate combinations of antecedent adjectives and key words, it was possible to categorize the elemental mechanical functions of each of the individual parts studied in this failure history investigation. It is believed that most machine parts used throughout industry could be classified using proper combinations from Tables II and III, although certain cases may exist for which an additional key word or antecedent adjective might be required.

TABLE II. LIST OF KEY WORDS USED IN DEFINING ELEMENTAL MECHANICAL FUNCTIONS

Absorbing	Guiding	Rolling
Amplifying	Increasing	Sealing
Attaching	Indicating	Sensing
Balancing	Insulating	Shielding
Clutching	Latching	Sliding
Conducting	Lighting	Spacing
Constraining	Limiting	Stabilizing
Coupling	Linking	Storing
Covering	Maintaining	Streamlining
Damping	Partitioning	Supporting
Deflecting	Pivoting	Switching
Disconnecting	Pumping	Transferring
Dissipating	Reducing	Transforming
Distributing	Reinforcing	Transmitting
Fastening	Restoring	Viewing
Filtering		

TABLE III. AUXILIARY LIST OF ANTECEDENT ADJECTIVES USED IN DEFINING ELEMENTAL MECHANICAL FUNCTIONS		
Acceleration	Information	Power
Adjustable	Light	Pressure
Aerodynamic	Liquid	Protective
Contaminant	Lubricant	Removable
Continuous	Mass	Rigid
Displacement	Momentum	Shape
Electrical	Motion	Signal
Energy	Movable	Sound
Flexible	Oscillatory	Temporary
Force	Particulate	Torque
Friction	Permanent	Variable
Gas	Pneumatic	Velocity
Heat	Position	Viscous
Hydraulic		

The approximately 105 elemental functions used in the failure-experience matrix associated with this investigation are shown in Table IV. The elemental mechanical functions are listed in order of their frequency of occurrence in this study.

TABLE IV. ELEMENTAL MECHANICAL FUNCTIONS INCLUDED IN THE FAILURE-EXPERIENCE MATRIX

Rank	Elemental Mechanical Function	No. of Occurrences
1	Supporting	206
2	Attaching	108
3	Motion Constraining	98
4	Force Transmitting	93
5	Sealing	78
6	Friction Reducing	71
7	Protective Covering	55
8	Liquid Constraining	54
9	Pivoting	53

TABLE IV - Continued		
Rank	Elemental Mechanical Function	No. of Occurrences
10	Torque Transmitting	40
11	Pressure Supporting	38
12	Oscillatory Sliding	37
13	Shielding	26
	Sliding	26
	Energy Transforming	26
14	Removable Fastening	20
	Limiting	20
15	Electrical Conducting	18
16	Contaminant Constraining	17
	Linking	17
	Continuous Rolling	17
	Liquid Transferring	17
17	Force Amplifying	16
	Power Transmitting	16
18	Covering	13
	Oscillatory Rolling	13
19	Energy Absorbing	12
	Light Transmitting	12
	Viewing	12
20	Energy Dissipating	10
	Guiding	10
	Latching	10
	Electrical Switching	10
	Liquid Switching	10
	Stabilizing	10
21	Gas Constraining	9
	Permanent Fastening	9
	Pressure Increasing	9
	Streamlining	9
22	Motion Reducing	8

TABLE IV - Continued		
Rank	Elemental Mechanical Function	No. of Occurrences
23	Filtering	6
	Lighting	6
	Pumping	6
	Gas Transferring	6
	Aerodynamic Force Transmitting	6
	Motion Transmitting	6
	Signal Transmitting	6
24	Motion Damping	5
	Force Distributing	5
	Reinforcing	5
	Pressure Sensing	5
	Information Transmitting	5
	Unknown	5
25	Coupling	4
	Displacement Indicating	4
26	Clutching	3
	Fastening	3
	Information Indicating	3
	Position Indicating	3
	Movable Lighting	3
	Partitioning	3
	Position Restoring	3
	Flexible Spacing	3
27	Electrical Amplifying	2
	Adjustable Attaching	2
	Shape Constraining	2
	Deflecting	2
	Disconnecting	2
	Electrical Limiting	2
	Motion Limiting	2
	Pressure Limiting	2
	Sensing	2
	Force Sensing	2
	Spacing	2
	Temporary Supporting	2
	Gas Switching	2
	Electrical Transforming	2
	Power Absorbing	1
	Sound Absorbing	1
	Information Attaching	1
	Constraining	1

TABLE IV - Continued		
Rank	Elemental Mechanical Function	No. of Occurrences
28	Flexible Coupling	1
	Removable Covering	1
	Damping	1
	Electrical Distributing	1
	Load Distributing	1
	Gas Guiding	1
	Pressure Indicating	1
	Electrical Insulating	1
	Sound Insulating	1
	Temporary Latching	1
	Force Limiting	1
	Force Maintaining	1
	Variable Position Maintaining	1
	Liquid Pumping	1
	Electrical Reducing	1
	Rolling	1
	Position Sensing	1
	Energy Storing	1
	Liquid Storing	1
	Flexible Supporting	1
	Switching	1
	Pressure-to-Torque Transforming	1
	Electrical Transmitting	1
	Flexible Motion Transmitting	1
	Flexible Torque Transmitting	1
	Torque Limiting	1

It may be noted that a large number of the elemental mechanical functions were only found once in all of the cases studied, but for the "supporting" function 206 occurrences were observed. To help understand the use and meaning of these elemental mechanical functions, a glossary of key words is included as Appendix II of this report.

CORRECTIVE ACTIONS

In this investigation it was possible to classify all of the corrective actions into approximately 35 broad categories. In other investigations it would probably be necessary to add other corrective action categories. For larger failure-experience populations it might be advantageous to utilize more specific corrective action categories which would result in more categories with smaller populations in most cells of the failure experience matrix. Based on a careful consideration of these factors,

the 35 generalized corrective actions deemed appropriate for the present study are shown below in Table V. The corrective actions are listed in order of their frequency of occurrence in this study.

TABLE V. CORRECTIVE ACTIONS INCLUDED IN THE FAILURE-EXPERIENCE MATRIX

Rank	Corrective Action	No. of Occurrences
1	Improved Part	173
2	Direct Replacement	153
3	Change of Material	73
4	Supplemental Part	71
5	Improved Instructions to Field Personnel	68
6	Changed Dimensions	59
7	Changed Loading on Part	31
8	Applied Surface Coating	30
8	Changed Mechanism of Operation	30
9	Relocated or Repositioned Part	25
10	Repaired	22
11	Changed Method of Attachment	20
12	Changed Manufacturing Procedure	19
13	Reinforced Part	16
14	Eliminated Part	15
15	Strengthened Part	13
16	Changed Method or Frequency of Lubrication	11
17	Changed Vendor	10
18	Added Adhesive or Changed Adhesive Material	9
18	Improved Quality Control	9

TABLE V - Continued		
Rank	Corrective Action	No. of Occurrences
19	Changed Lubricant Type or Added Lubricant	7
20	Improved Run-In Procedure	6
21	Applied Surface Treatment	5
	Added Sealant	5
22	Added or Changed Locking Feature	3
	Adjusted Part	3
	Provided Drain	3
	More Easily Replaceable	3
	Changed to Correct Part	3
23	Improved Lubrication	2
	Made Parts Interchangeable for Inventory	2
24	Relaxed Replacement Criteria	1
	Revised Procurement Specifications	1
	Provided Means for Proper Inspection	1
	Changed Electrical Characteristics	1

It may be observed that four of the corrective actions were used only once among the more than 500 parts studied in this investigation. The most often used corrective action, "improved part", was employed 175 times, but in most cases the engineering details of how the part was improved were unavailable. The second ranked category, "direct replacement", might be questioned as to whether it is truly a corrective action to replace a failed part with another just like the one that failed, since such a corrective action must be viewed as temporary. Thus the third ranked category, "change of material", with 73 occurrences, is the most frequently used corrective action which is clearly a known design alteration intended to solve a failure problem. To help understand the use and meaning of each of these actions, a glossary of corrective actions is included as Appendix III of this report.

REVIEW AND ORGANIZATION OF FAILURE CASE HISTORY DATA FOR INSERTION INTO FAILURE-EXPERIENCE MATRIX

The 240 failure case histories supplied for this investigation by the Eustis Directorate were selected to include failures from utility, cargo, attack, observation, and training helicopters produced by four different manufacturers. The problems were chosen from many different regions of the helicopters to insure that a large variety of failure modes and functions would be included. The only parts deliberately excluded from this study were the internal engine components.

The majority of the failure case histories were documented in three reports [1,2,3] [1] concerning reliability and maintainability, and the remainder were extracted from engineering change proposals (ECP's), task reports, and product improvement reports. Most of the failure cases were supplemented by drawings and other documents including ECP's, modification work orders (MWO's), engineering orders (EO's), specifications, teardown analysis reports, disassembly inspection reports, testing reports, and letter communications. In addition, Parts Manuals (TM 55-1520-XXX-34P) were supplied for assistance in locating and identifying parts from manufacturers' numbers or from federal stock numbers.

FAILURE MODE ASSESSMENT

To assemble information for insertion into the failure-experience matrix, the failure description contained in each case history packet had to be examined to determine what parts failed and how the failures occurred. It should be emphasized that the accounts of the failures were generally not restricted to a single failure or to a single component. In many cases, the histories contained a summary of failures that occurred in a general system or a summary of failures for a component that had been used in a variety of different locations and applications. This was typical for fasteners, bearings, door hardware, hydraulic components, and corrosion problems. The initial failure and the resulting secondary failures were often described together, and often it was not possible to deduce the order in which failures occurred.

The initial attempt to associate a failure mode with each broad case history had to be abandoned because the various parts included in a given case history often failed by widely different failure modes. Thus, each individual part which failed or malfunctioned was separately listed and identified by a number indicating the case history and an accompanying letter to distinguish it from other parts in the same case history.

Based upon the documented account and the application involved, the most

[1] Numbers in brackets designate references at end of report.

probable failure mode(s) were deduced for each part. The key words in the failure description frequently required translation into more specific failure mode nomenclature. For example, descriptions with such key words as broken, loose, missing, cracked, sheared, dented, punctured, leaking, separated, frozen, scratched, gouged, pitted, rough, grooved, deteriorating, torn, swollen, frayed, scuffed, clogged, damaged, inoperable, malfunctional, internal failure, excessive vibration, discolored, crazed, out of tolerance, contaminated, etc., are not directly correlated on a one-to-one basis with the categories in general usage for the more familiar failure modes. A few failures were listed as unknown or undetermined. Such listings were required for 37 items and portions of seven other items. The failure mode categories are listed in Table I.

ELEMENTAL MECHANICAL FUNCTION CLASSIFICATION

From the name of the part, its proximity to other parts and, in some cases, a description of its operation, the functions performed by the parts were deduced. Independent evaluations were made by several different individuals, each of whom classified the function of all parts included in this study. These independent classifications were then compared and discussed at length to select the best description for the functions of each component. By studying the list of functions, a set of key words and descriptive modifiers were chosen. The key words were present participles, i.e., "ing" verb forms used as adjectives. The functions of all the components were then reclassified using these selected terms. In those cases where the key word formed a group that was clearly too broad in scope, one or more descriptive words were combined with the key word to form subgroups which, in effect, were treated as distinct and separate functions. For example, windshields, shafts, bolts, and radios could all be classed as transmitting members, but they transmit significantly different quantities, i.e., light, power, force, and information, respectively. Thus, in order to distinguish more specific functions, antecedent adjectives were used with the key word to form separate function categories, such as light transmitting, power transmitting, force transmitting, etc.

Any attempt to classify components by their elemental mechanical functions in a given application may be subject to debate. It becomes necessary to decide whether to include only one or two main functions or every conceivable function that a part might perform, either intentionally or unintentionally. The problem of redundancy in terminology is also difficult to avoid. In this investigation, it was decided to include all of the more important functions and not to be greatly concerned with redundancy. This approach has provided categories that are suitable for usage in the failure experience matrix, but these categories are by no means unique. Other classification systems, using both smaller and larger numbers of categories, were tried but none appeared to have any advantage over the selected classification. The key words and antecedent adjectives are presented in Tables II and III, respectively. The

specific elemental mechanical functions used in the matrix are given in Table IV.

CORRECTIVE ACTION DETERMINATION

The actions taken to correct failures or deficiencies were usually indicated in the contents of the case history packets. The documentation generally indicated the technical procedure to incorporate the corrective action and a summary of what the proposed action involved. Some case histories were accompanied by other documents that provided more detailed descriptions of the corrective actions. These supporting documents were primarily engineering change proposals, engineering orders and drawings, with some test reports, memos and letters. In the case histories which dated back into the middle to late 1960's, where the elapsed time had provided a period of evaluation for the corrective action, the effective or low-performance improvements were usually noted, often accompanied by the necessity for reopening the case to subsequent corrective actions. The effectiveness was not generally indicated for the successful or the more recent actions. Some corrective actions were rejected, and for others approval was still pending at the last account. For these cases, the corrective action effectiveness could not be indicated. The reasons for rejection were often economic, but frequently they were not specified.

A preliminary review suggested a number of obvious corrective action categories. These were used as a base upon which additions and changes were incorporated as necessary. Many case histories were not specific on details of the corrective changes. Attempts to procure additional information were not always successful, since some documents were out of date and could not be obtained. The cases for which corrective actions were indicated by an ECP, EO, or other approved procedure, but for which details were not available, were classed as "improved part".

A complication was encountered in those cases where the corrective action did not directly involve a change to the failed part but involved changes to surrounding or adjacent parts. For those cases, the corrective action descriptions were amended by adding "associated part" to the appropriate regular categories. These were arbitrarily treated the same as a direct action when inserted into the matrix, but with a larger failure data base they could be treated as separate categories. Thus it is important to note that the part that fails is not always the part requiring the remedial action.

After the corrective actions were sorted into the initially chosen categories, it was observed that several categories were relatively close in meaning and might be combined, especially if one or both categories contained only a small number of occurrences. For example, the final categories "Relocated or Repositioned Part" and "Changed Method or Frequency of Lubrication" resulted from such combinations. The main

features of the corrective actions are preserved in all of these combinations. The final list of 35 corrective actions is given in Table V.

The mere fact that a corrective action was proposed, or even used, for remedying a failure condition does not provide all the essential information. It is important to know which actions produce a demonstrated improvement in performance. Unfortunately, such information was available for a relatively small number of failed parts in this study. The basis and effectiveness of the corrective actions were noted where the information was available by using a sequence of letters following the corrective action listing. The basis is divided into four categories: used, tested, not used, and rejected. The effectiveness is qualitatively designated as: improvement, no improvement, or unknown. While the effectiveness is the primary interest, it is also useful to know the basis for determining the effectiveness.

COMPILATION OF DATA

The failure modes, elemental mechanical functions, and corrective actions that have been attributed to each of the more than five hundred parts have been assembled and are displayed in Table XIV in Appendix IV. This table contains all the essential information for the failure experience matrix, plus the basis/effectiveness classification of the corrective actions and some descriptive details for many of the actions.

The whole failure-experience matrix is difficult to present effectively, but it can be displayed piecewise by taking slices through the matrix parallel to two coordinate axes which intersect the third coordinate axis at selected locations. Since the matrix is composed of numerous information cells, a slice through a layer of cells in the matrix would reveal the contents of all cells within that layer. Thus, by taking slices parallel to the Failure Mode and Elemental Mechanical Function axes and intersecting the Corrective Action axis at each of its discrete values, in turn, it is possible to display the contents of the entire cell-matrix in a series of two-dimensional plots. In these two-dimensional information cells, representing all combinations of Failure Modes and Functions for each corrective action, it only remains to list the specific parts appropriate to each cell. This was done by recording the identifying number-letter combination for each part in the appropriate block. A sample of one of these slices through the failure-experience matrix for a plane cutting all the "change of material" corrective action cells is given in Table XV of Appendix IV. This, combined with a similar table for each of the other 34 corrective actions, represents the entire matrix.

ANALYSIS OF FAILURE-EXPERIENCE MATRIX

Having completed the task of reviewing, sorting, organizing and partitioning the information available, and inserting it into the failure-experience matrix with the aid of a digital computer, it remained to analyze the results of this effort. The magnitude of the task may be illustrated by recalling that the failure-experience matrix contained approximately 147,000 information cells, of which approximately 5 percent were populated. The data processing was accomplished through a combination of computer-augmented storage-and-retrieval together with manual efforts to compile and plot selected information. Since it is impractical to attempt a display of the entire failure-experience matrix, only the most pertinent and interesting aspects of these results are presented here.

OVERALL ANALYSIS OF RESULTS

Three series of graphical results are depicted in Figures 2 through 101. In Series I, which includes Figures 2 through 33, the frequency of usage of all corrective actions is plotted for each failure mode observed in the study. Series II plots, given in Figures 34 through 67, show the frequency of occurrence of all impaired elemental mechanical functions associated with each of the imposed corrective actions. The plots of Series III, included in Figures 68 through 101, illustrate the frequency of occurrence of failure modes associated with each corrective action used. For all three series the bars used in displaying the results have been partitioned into three regions to qualitatively show the effectiveness of corrective actions. These regions are: (1) corrective actions for which an <u>improvement</u> in failure prevention <u>was noted</u>, (2) corrective actions for which it was noted that <u>no improvement</u> in failure prevention <u>ensued</u>, and (3) corrective actions for which <u>no information was available</u> about the result of the action in terms of failure prevention. Unfortunately, the documentation available did not provide information which would allow a more quantitative assessment of the corrective action effectiveness. Further subdivision of the three qualitatively partitioned regions noted above was experimented with in the process of analyzing the results, but no additional useful observations could be drawn from this effort. The substantial percentage of all corrective actions for which no information was available about the failure prevention consequences of the action indicates a strong need for improved reporting and two-way failure accounting trails. Such information can only be obtained by better documentation of the basic failure mode, engineering evaluation of the problem, corrective action proposed, when and how the corrective actions were implemented and, especially, quantitative results of the corrective action in terms of failure statistics following implementation of the action.

From the Series I plots shown in Figures 2 through 33, it may be observed that the corrective actions, "improved part" and "direct replacement",

constituted much of the activity associated with the occurrence of a given failure mode. The category, "improved part", includes all of the failure cases for which no detailed information was available about the nature of the corrective action taken. The documentation simply declared that the part was modified or improved. The "direct replacement" category indicates that a failed part was replaced with another identical part with the same probability of failure. These two categories are of little direct use in this study except to note that with better documentation the "improved part" category would be eliminated from the failure-experience matrix because its population would be dispersed to more specific corrective action categories. Unfortunately, information of significance may remain hidden in the "improved part" category until more specific data can be obtained.

In studying the results of the Series I plots, shown in Figures 2 through 33, it is of interest to note the more frequently used correction actions associated with each failure mode observed in this investigation. Table VI lists the corrective actions employed at least ten times for a given failure mode. It should be observed that insight can be gained from Table VI with respect to which corrective actions are more frequently used, but the effectiveness of each corrective action is more elusive.

TABLE VI. CORRECTIVE ACTIONS WHICH WERE USED AT LEAST TEN TIMES FOR A SPECIFIED FAILURE MODE

Failure Mode (Listed in order of frequency of occurrence)	Corrective Action	No. of Occurrences of Corrective Action			
		Total	With Improvement	Improvement Unknown	No Improvement
1. Wear	1. Improved Part	80	2	67	11
	2. Direct Replacement	51	0	0	51
	3. Change of Material	35	3	28	4
	4. Supplemental Part	32	1	27	4
	5. Improved Instructions to Field Personnel	27	0	25	2
	6. Changed Dimensions	22	1	20	1
	7. Applied Surface Coating	10	2	8	0
2. Ductile Rupture	1. Improved Part	73	9	58	6
	2. Direct Replacement	41	0	0	41
	3. Supplemental Part	29	2	27	0
	4. Changed Dimensions	29	1	27	1
	5. Change of Material	26	2	21	3

TABLE VI - Continued						
Failure Mode (Listed in order of frequency of occurrence)	Corrective Action	No. of Occurrences of Corrective Action				
		Total	With Improvement	Improvement Unknown	No Improvement	
2. Ductile Rupture (cont'd)	6. Improved Instructions to Field Personnel	21	0	21	0	
	7. Changed Mechanism of Operation	14	2	12	0	
	8. Changed Loading on Part	11	1	10	0	
	9. Changed Method of Attachment	10	0	10	0	
3. Fatigue	1. Improved Part	57	6	47	4	
	2. Direct Replacement	30	0	0	30	
	3. Changed Dimensions	30	0	30	0	
	4. Supplemental Part	29	3	26	0	
	5. Change of Material	26	0	25	1	
	6. Improved Instructions to Field Personnel	25	0	23	2	
	7. Changed Loading on Part	15	2	13	0	
	8. Changed Mechanism of Operation	14	2	11	1	
	9. Reinforced Part	14	0	14	0	
	10. Repaired	11	0	0	11	
	11. Changed Method of Attachment	10	0	10	0	
4. Leakage	1. Improved Part	57	12	37	8	
	2. Direct Replacement	43	0	0	43	
	3. Change of Material	18	1	11	6	
	4. Supplemental Part	16	4	10	2	
	5. Improved Instructions to Field Personnel	15	0	15	0	
5. Yielding	1. Improved Part	27	0	22	5	
	2. Changed Dimensions	21	0	20	1	
	3. Direct Replacement	20	0	0	20	
	4. Improved Instructions to Field Personnel	17	0	17	0	
	5. Supplemental Part	16	0	16	0	
	6. Changed Loading on Part	11	0	11	0	

TABLE VI - Continued						
Failure Mode (Listed in order of frequency of occurrence)	Corrective Action	No. of Occurrences of Corrective Action			
		Total	With Improvement	Improvement Unknown	No Improvement
6. Impact	1. Improved Part	32	1	28	3
	2. Direct Replacement	23	0	0	23
	3. Changed Dimensions	18	0	17	[illegible]
	4. Supplemental Part	11	1	10	0
7. Corrosion	1. Improved Part	25	0	22	3
	2. Improved Instructions to Field Personnel	16	0	16	0
	3. Direct Replacement	15	0	0	15
	4. Applied Surface Coating	14	3	11	0
8. Bonding Failure	1. Improved Part	17	0	17	0
	2. Supplemental Part	12	1	7	4
	3. Improved Instructions to Field Personnel	12	0	12	0
	4. Direct Replacement	11	0	0	11
9. Seizure	1. Improved Part	11	0	10	1
10. Surface Fatigue	1. Improved Part	11	0	7	4
11. Galling	1. Change of Material	12	0	12	0
12. Scoring	1. Improved Part	13	0	12	1
13. Change in Material Property	None				
14. Erosion	None				
Each of the remaining 26 failure modes occurred fewer than 10 times in the investigation reported here.					

The Series II plots, shown in Figures 34 through 67, may be studied to determine the more frequently failing elemental mechanical functions to

which specified actions were applied in the investigation. Table VII lists under each corrective action all of the elemental mechanical functions for which the corrective action was employed in at least ten different cases.

TABLE VII. ELEMENTAL MECHANICAL FUNCTIONS FOR WHICH FAILURE WAS ADDRESSED AT LEAST TEN TIMES BY USE OF A SPECIFIED CORRECTIVE ACTION

Corrective Action (Listed in order of frequency of occurrence)	Elemental Mechanical Function	No. of Cases of Given Elemental Mechanical Function			
		Total	With Improvement	Improvement Unknown	No Improvement
1. Improved Part	Supporting	73	4	61	8
	Sealing	44	10	30	4
	Attaching	40	4	33	3
	Motion Constraining	38	1	33	4
	Force Transmitting	35	2	31	2
	Pressure Supporting	32	11	16	5
	Liquid Constraining	29	9	15	5
	Friction Reducing	24	0	22	2
	Pivoting	19	0	19	0
	Torque Transmitting	16	0	12	4
	Energy Transforming	15	2	11	2
	Continuous Rolling	14	0	11	3
	Protective Covering	13	0	12	1
	Oscillatory Sliding	12	0	12	0
	Force Amplifying	11	2	7	2
	Liquid Switching	11	4	7	0
	Energy Absorbing	10	0	10	0
	Electrical Conducting	10	0	10	0
	Limiting	10	2	7	1
2. Direct Replacement	Supporting	50	0	0	50
	Attaching	33	0	0	33
	Sealing	29	0	0	29
	Motion Constraining	24	0	0	24
	Force Transmitting	22	0	0	22
	Liquid Constraining	20	0	0	20
	Pressure Supporting	16	0	0	16
	Pivoting	15	0	0	15
	Friction Reducing	14	0	0	14

TABLE VII - Continued					
		No. of Cases of Given Elemental Mechanical Function			
Corrective Action (Listed in order of frequency of occurrence)	Elemental Mechanical Function	Total	With Improvement	Improvement Unknown	No Improvement
2. Direct Replacement (cont'd)	Protective Covering	12	0	0	12
	Contaminant Constraining	10	0	0	10
3. Change of Material	Supporting	37	1	34	2
	Oscillatory Sliding	18	1	16	1
	Motion Constraining	16	1	15	0
	Protective Covering	15	4	11	0
	Attaching	14	0	12	2
	Friction Reducing	10	0	10	0
4. Supplemental Part	Supporting	21	0	17	4
	Attaching	18	0	17	1
	Protective Covering	16	2	14	0
	Force Transmitting	16	0	16	0
	Sealing	15	3	10	2
	Motion Constraining	13	1	9	3
	Friction Reducing	10	0	6	4
	Sliding	10	3	7	0
5. Improved Instructions to Field Personnel	Supporting	31	0	31	0
	Attaching	15	0	15	0
	Sealing	12	0	12	0
	Protective Covering	11	0	11	0
	Motion Constraining	10	0	10	0
	Force Transmitting	10	0	10	0
6. Changed Dimensions	Supporting	29	0	29	0
	Attaching	24	0	24	0
	Protective Covering	10	0	9	1
7. Applied Surface Coating	Supporting	15	1	14	0
	Attaching	10	0	10	0
8. Changed Loading on Part	Attaching	18	1	17	0
	Supporting	13	5	8	0
9. Changed Mechanism of Operation	None	--	--	--	--

TABLE VII - Continued					
Corrective Action (Listed in order of frequency of occurrence)	Elemental Mechanical Function	No. of Cases of Given Elemental Mechanical Function			
		Total	With Improvement	Improvement Unknown	No Improvement
10. Relocated or Repositioned Part	Supporting	10	0	9	1
	Force Transmitting	10	0	10	0
11. Repaired	Supporting	16	0	0	16
12. Changed Method of Attachment	Attaching	10	0	10	0
13. Changed Manufacturing Procedure	Supporting	10	0	10	0
14. Reinforced Part	Supporting	13	0	13	0
Each of the remaining 21 corrective actions occurred fewer than 10 times in the investigation reported here.					

The results presented in the Series III plots of Figures 68 through 101 represent a useful cross-plotting of the Series I results. In the Series III results, all of the failure modes for which a given corrective action was employed are shown for each corrective action. Table VIII lists under each corrective action all of the failure modes for which the corrective action was employed in at least ten different cases.

TABLE VIII. FAILURE MODES WHICH WERE ADDRESSED AT LEAST TEN TIMES BY USE OF A SPECIFIED CORRECTIVE ACTION

Corrective Action (Listed in order of frequency of occurrence)	Failure Mode	No. of Cases of Given Failure Mode: Total	With Improvement	Improvement Unknown	No Improvement
1. Improved Part	Wear	80	2	67	11
	Ductile Rupture	73	9	58	6
	Leakage	57	12	37	8
	Fatigue	55	6	46	3
	Impact	32	1	28	3
	Yielding	27	0	22	5
	Corrosion	25	0	22	3
	Unknown	19	4	14	1
	Bonding Failure	17	0	17	0
	Scoring	13	0	12	1
	Surface Fatigue	11	0	7	4
	Seizure	11	0	10	1
2. Direct Replacement	Wear	51	0	0	51
	Leakage	43	0	0	43
	Ductile Rupture	41	0	0	41
	Fatigue	30	0	0	30
	Impact	23	0	0	23
	Yielding	20	0	0	20
	Unknown	16	0	0	16
	Corrosion	15	0	0	15
	Bonding Failure	11	0	0	11
3. Change of Material	Wear	35	3	28	4
	Ductile Rupture	26	2	21	3
	Fatigue	26	0	25	1
	Leakage	18	1	11	6
	Galling	12	0	12	0
4. Supplemental Part	Wear	32	1	27	4
	Ductile Rupture	29	2	27	0
	Fatigue	29	3	26	0
	Yielding	16	0	16	0
	Leakage	16	4	10	2
	Bonding Failure	12	1	7	4
	Impact	11	1	10	0

TABLE VIII - Continued

Corrective Action (Listed in order of frequency of occurrence)	Failure Mode	No. of Cases of Given Failure Mode: Total	With Improvement	Improvement Unknown	No Improvement
5. Improved Instructions to Field Personnel	Wear	27	0	25	2
	Fatigue	25	0	23	2
	Ductile Rupture	21	0	21	0
	Yielding	17	0	17	0
	Corrosion	16	0	16	0
	Leakage	15	0	15	0
	Bonding Failure	12	0	12	0
6. Changed Dimensions	Fatigue	30	0	30	0
	Ductile Rupture	29	2	26	1
	Wear	22	1	20	1
	Yielding	21	0	20	1
	Impact	18	0	17	1
7. Applied Surface Coating	Corrosion	14	3	11	0
	Wear	10	2	8	0
8. Changed Loading on Part	Fatigue	15	2	13	0
	Yielding	11	0	11	0
	Ductile Rupture	11	1	10	0
9. Changed Mechanism of Operation	Ductile Rupture	14	2	11	1
	Fatigue	10	1	8	1
10. Relocated or Repositioned Part	None				
11. Repaired	Fatigue	11	0	0	11
12. Changed Method of Attachment	Ductile Rupture	10	0	10	0
	Fatigue	10	0	10	0
13. Changed Manufacturing Procedure	None				
14. Reinforced Part	Fatigue	14	0	14	0
	Ductile Rupture	13	0	13	0

Each of the remaining 21 corrective actions occurred fewer than 10 times in the investigation reported here.

While the information presented above is useful, it includes a large amount of data for which the effectiveness of the corrective action is unknown. It might be reasoned that, if ten or more cases exist in which a certain corrective action was applied to solve a given failure mode or to mitigate the impairment of a particular function, there must have been justification for using the corrective action even if nothing was documented to indicate effectiveness. It might be further hypothesized that, if no improvement had been observed, this fact probably would have been documented. Thus, the results given in Tables VI, VII, and VIII may be used on this rather subjective basis to draw general qualitative observations if it is kept firmly in mind that such observations are speculative and subject to change.

Following the same line of reasoning, the entire failure-experience matrix was searched for information cells which contained eight or more cases. This information, shown below in Table IX, gives a good indication of which problems have received the most concentrated attention, together with a qualitative assessment of the effectiveness of the corrective actions employed.

TABLE IX. INFORMATION CELLS IN THE FAILURE-EXPERIENCE MATRIX WHICH CONTAIN EIGHT OR MORE CASES

Corrective Action	Failure Mode	Elemental Mechanical Function	No. of Cases: Total	With Improvement	Improvement Unknown	No Improvement
1. Improved Part	Wear	Supporting	38	0	32	6
	Wear	Motion Constraining	35	0	31	4
	Fatigue	Supporting	32	4	27	1
	Ductile Rupture	Supporting	30	2	26	2
	Leakage	Sealing	28	8	16	4
	Leakage	Pressure Supporting	27	9	13	5
	Ductile Rupture	Attaching	25	2	20	3
	Fatigue	Attaching	25	3	20	2
	Leakage	Liquid Constraining	24	8	12	4
	Wear	Friction Reducing	23	0	21	2
	Wear	Force Transmitting	19	0	19	0

TABLE IX - Continued						
			No. of Cases			
Corrective Action	Failure Mode	Elemental Mechanical Function	Total	With Improvement	Improvement Unknown	No Improvement
1. Improved Part (Cont'd)	Corrosion	Supporting	16	0	13	3
	Wear	Continuous Rolling	16	0	11	5
	Yielding	Attaching	14	0	12	2
	Wear	Pivoting	13	0	13	0
	Wear	Sealing	13	1	12	0
	Wear	Attaching	12	0	11	1
	Impact	Attaching	11	1	9	1
	Wear	Oscillatory Sliding	11	0	11	0
	Impact	Supporting	11	0	10	1
	Wear	Liquid Constraining	10	2	6	2
	Ductile Rupture	Sealing	10	4	5	1
	Leakage	Liquid Switching	10	4	6	0
	Leakage	Force Transmitting	10	2	6	2
	Yielding	Supporting	10	0	8	2
	Leakage	Force Amplifying	9	2	5	2
	Surface Fatigue	Motion Constraining	9	0	6	3
	Corrosion	Motion Constraining	9	0	6	3
	Surface Fatigue	Supporting	9	0	6	3
	Wear	Pressure Supporting	9	1	6	2
	Wear	Energy Absorbing	8	0	0	8
	Ductile Rupture	Liquid Constraining	8	3	3	2
	Surface Fatigue	Continuous Rolling	8	0	5	3
	Corrosion	Continuous Rolling	8	0	5	3
	Bonding Failure	Supporting	8	0	8	0

TABLE IX - Continued

Corrective Action	Failure Mode	Elemental Mechanical Function	No. of Cases: Total	With Improvement	Improvement Unknown	No Improvement
2. Direct Replacement	Wear	Supporting	24	0	0	24
	Wear	Motion Constraining	23	0	0	23
	Ductile Rupture	Attaching	18	0	0	18
	Leakage	Sealing	17	0	0	17
	Leakage	Liquid Constraining	16	0	0	16
	Fatigue	Attaching	15	0	0	15
	Wear	Friction Reducing	15	0	0	15
	Yielding	Attaching	14	0	0	14
	Ductile Rupture	Supporting	13	0	0	13
	Leakage	Pressure Supporting	13	0	0	13
	Wear	Attaching	11	0	0	11
	Bonding Failure	Supporting	10	0	0	10
	Impact	Supporting	10	0	0	10
	Wear	Pivoting	10	0	0	10
	Wear	Oscillatory Sliding	9	0	0	9
	Wear	Force Transmitting	9	0	0	9
	Fatigue	Supporting	8	0	0	8
	Impact	Attaching	8	0	0	8
3. Change of Material	Wear	Supporting	26	1	25	0
	Wear	Oscillatory Sliding	18	1	16	1
	Wear	Motion Constraining	16	1	15	0
	Fatigue	Supporting	13	0	12	1
	Wear	Friction Reducing	10	0	10	0
	Galling	Supporting	9	0	9	0
	Leakage	Supporting	9	0	8	1

TABLE IX - Continued						
			No. of Cases			
Corrective Action	Failure Mode	Elemental Mechanical Function	Total	With Improvement	Improvement Unknown	No Improvement
3. Change of Material (cont'd)	Galling	Oscillatory Sliding	8	0	8	0
	Leakage	Oscillatory Sliding	8	0	8	0
	Ductile Rupture	Supporting	8	0	7	1
	Seizure	Oscillatory Sliding	8	0	8	0
	Seizure	Supporting	8	0	8	0
4. Supplemental Part	Fatigue	Attaching	13	0	13	0
	Wear	Motion Constraining	13	1	9	3
	Wear	Supporting	12	0	8	4
	Ductile Rupture	Attaching	11	0	10	1
	Wear	Friction Reducing	10	0	6	4
	Fatigue	Protective Covering	8	1	7	0
	Wear	Sliding	8	1	7	0
5. Improved Instructions to Field Personnel	Fatigue	Supporting	18	0	18	0
	Ductile Rupture	Supporting	13	0	13	0
	Yielding	Supporting	10	0	10	0
	Corrosion	Supporting	10	0	10	0
	Fatigue	Attaching	9	0	9	0
	Wear	Motion Constraining	9	0	9	0
	Bonding Failure	Supporting	9	0	9	0
6. Changed Dimensions	Fatigue	Attaching	16	0	16	0
	Fatigue	Supporting	16	0	16	0
	Ductile Rupture	Supporting	11	0	11	0

TABLE IX - Continued						
			No. of Cases			
Corrective Action	Failure Mode	Elemental Mechanical Function	Total	With Improvement	Improvement Unknown	No Improvement
6. Changed Dimensions (cont'd)	Ductile Rupture	Attaching	10	0	10	0
	Wear	Supporting	9	0	9	0
7. Applied Surface Coating	Corrosion	Supporting	10	1	9	0
	Corrosion	Attaching	8	0	8	0
8. Changed Loading on Part	Fatigue	Attaching	13	1	12	0
	Ductile Rupture	Attaching	9	1	8	0
	Yielding	Attaching	8	0	8	0
9. Repaired	Fatigue	Supporting	9	0	0	9
	Bonding Failure	Supporting	9	0	0	9
10. Reinforced Part	Fatigue	Supporting	9	0	9	0
	Ductile Rupture	Supporting	8	0	8	0
Cells for all other corrective actions have fewer than 8 occurrences.						

ANALYSIS OF DATA FOR WHICH THE CORRECTIVE ACTIONS RESULTED IN AN IMPROVEMENT

While the overall results discussed above contain many unknown factors, there is included in the overall data a significant subpopulation of failure cases for which the corrective actions employed resulted in a definite improvement in failure prevention response. This subpopulation is of greater interest than the overall population because no speculation is necessary to associate improved performance with the corrective action employed. Unfortunately, however, even with this selected subpopulation it is not possible to define a quantitative figure of merit by which corrective action effectiveness can be graded.

Table X records all of the cases investigated for which an improvement in failure prevention response was observed as a result of applying a specified corrective action. One of the objectives of the analysis was to aggregate the most successful solutions to common failure modes at their highest level of applicability. This objective is accomplished in Table X by aggregating all of the elemental mechanical functions associated with a corrective action addressed to each of the pertinent failure modes. It may be noted, also, that one or more failure case reference numbers are shown with each entry in this table. These reference numbers are keyed to Table XIV in Appendix IV where each of the failure cases is briefly described. These same reference numbers are also keyed to the failure case history packets, so that all available information about any of the entries in Table X can be quickly retrieved.

TABLE X. CORRECTIVE ACTIONS WHICH IMPROVED FAILURE RESISTANCE OF CERTAIN ELEMENTAL MECHANICAL FUNCTIONS FOR EACH OBSERVED FAILURE MODE

Failure Mode (in order of frequency of occurrence)	Corrective Action	Aggregation of Elemental Mech. Functions	Failure Case Reference Numbers
1. Wear	A. Improved Part	a) Liquid Constraining	13a, 38a
		b) Sealing	13a
		c) Liquid Transferring	38a
	B. Change of Material	a) Contaminant Constraining	60b
		b) Motion Constraining	124a
		c) Coupling	124a
		d) Sealing	60b
		e) Sliding	124a
		f) Oscillatory Sliding	91c
		g) Supporting	91c
		h) Motion Transmitting	124a
		i) Torque Transmitting	124a
	C. Supplemental Part	a) Motion Constraining	124a
		b) Coupling	124a
		c) Sliding	124a
		d) Motion Transmitting	124a
		e) Torque Transmitting	124a
	D. Changed Dimensions	a) Contaminant Constraining	60b (2 uses)
		b) Sealing	60b (2 uses)

TABLE X - Continued			
Failure Mode (in order of frequency of occurrence)	Corrective Action	Aggregation of Elemental Mech. Functions	Failure Case Reference Numbers
1. Wear (Cont'd)	E. Applied Surface Coating	a) Linking	104
		b) Sealing	8a
		c) Shielding	8a
		d) Sliding	8a
		e) Force Transmitting	104
		f) Motion Transmitting	104
	F. Changed Loading on Part	a) Motion Constraining	29a,29b
		b) Pivoting	29b
		c) Friction Reducing	29a,29b
		d) Oscillatory Rolling	29a
		e) Sliding	29e,29f
		f) Oscillatory Sliding	29b
		g) Supporting	29a,29b, 29e
		h) Force Transmitting	29b,29e
		i) Torque Transmitting	29e,29f
	G. Changed Mechanism of Operation	a) Attaching	3c
		b) Motion Constraining	3c
		c) Friction Reducing	3c
		d) Rolling	3c
		e) Supporting	3c
	H. Changed Lubricant Type or Added Lubricant	a) Motion Constraining	124a (2 uses)
		b) Coupling	124a (2 uses)
		c) Sliding	124a (2 uses)
		d) Motion Transmitting	124a (2 uses)
		e) Torque Transmitting	124a (2 uses)
	I. Changed to Correct Part	a) Spacing	14a
2. Ductile Rupture	A. Improved Part	a) Attaching	38b,77j
		b) Contaminant Constraining	136
		c) Liquid Constraining	13a,38a, 77g
		d) Covering	136
		e) Limiting	9b

TABLE X - Continued			
Failure Mode (in order of frequency of occurrence)	Corrective Action	Aggregation of Elemental Mech. Functions	Failure Case Reference Numbers
2. Ductile Rupture (cont'd)	A. Improved Part (cont'd)	f) Pumping	77c (2 uses)
		g) Sealing	13a, 77j 136
		h) Supporting	9b, 38b, 77j
		i) Pressure Supporting	38a 77c (2 uses) 77g
		j) Liquid Transferring	38a, 77c, 77g
	B. Change of Material	a) Sound Absorbing	108
		b) Contaminant Constraining	60b
		c) Protective Covering	108
		d) Sound Insulating	108
		e) Sealing	60b
	C. Supplemental Part	a) Contaminant Constraining	124b
		b) Liquid Constraining	77g
		c) Sealing	124b
		d) Pressure Supporting	77g
		e) Liquid Transferring	77g
	D. Changed Dimensions	a) Contaminant Constraining	60b (2 uses)
		b) Sealing	60b (2 uses)
	E. Applied Surface Coating	a) Torque Transmitting	92a
	F. Changed Loading on Part	a) Attaching	29c
		b) Supporting	29c
	G. Changed Mechanism of Operation	a) Attaching	3c
		b) Motion Constraining	3c
		c) Limiting	9b
		d) Friction Reducing	3c
		e) Rolling	3c

TABLE X - Continued			
Failure Mode (in order of frequency of occurrence)	Corrective Action	Aggregation of Elemental Mech. Functions	Failure Case Reference Numbers
2. Ductile Rupture (cont'd)	G. Changed Mechanism of Operation (cont'd)	f) Supporting	3c,9b
	H. Relocated or Repositioned Part	a) Liquid Constraining	77g
		b) Pressure Supporting	77g
		c) Liquid Transferring	77g
	I. Changed Manufacturing Procedure	a) Power Transmitting	52d
		b) Torque Transmitting	52d
	J. Changed Method or Frequency of Lubrication	a) Torque Transmitting	92a
	K. Changed Vendor	a) Power Transmitting	52d
		b) Torque Transmitting	52d
	L. Improved Quality Control	a) Power Transmitting	52d
		b) Torque Transmitting	52d
3. Fatigue	A. Improved Part	a) Attaching	38b
		b) Liquid Constraining	38a,77g
		c) Limiting	9b
		d) Sealing	38b
		e) Supporting	9b,38b, 77j,182
		f) Pressure Supporting	77g
		g) Liquid Transferring	38a,77g
	B. Supplemental Part	a) Liquid Constraining	77g
		b) Protective Covering	113a
		c) Filtering	113a
		d) Lighting	18
		e) Pressure Supporting	77g
		f) Liquid Transferring	77g
		g) Energy Transforming	18
	C. Applied Surface Coating	a) Linking	104,261
		b) Stabilizing	9a
		c) Supporting	261
		d) Force Transmitting	9a,104, 261
		e) Motion Transmitting	104

TABLE X - Continued			
Failure Mode (in order of frequency of occurrence)	Corrective Action	Aggregation of Elemental Mech. Functions	Failure Case Reference Numbers
3. Fatigue (cont'd)	D. Changed Loading on Part	a) Attaching b) Lighting c) Supporting d) Energy Transforming	29c 18 29c 18
	E. Changed Mechanism	a) Limiting b) Supporting	9b 9b
	F. Relocated or Repositioned Part	a) Liquid Constraining b) Pressure Supporting c) Liquid Transferring	77g 77g 77g
	G. Changed Manufacturing Procedure	a) Power Transmitting b) Torque Transmitting	52d 52d
	H. Changed Vendor	a) Power Transmitting b) Torque Transmitting	52d 52d
	I. Improved Quality Control	a) Power Transmitting b) Torque Transmitting	52d 52d
	J. Changed to Correct Part	a) Attaching b) Supporting	81d 81d
4. Leakage	A. Improved Part	a) Force Amplifying b) Attaching c) Liquid Constraining d) Pumping e) Sealing f) Supporting g) Pressure Supporting	38c 77j 38e, 38g, 38h, 77e (3 uses) 77g 77c (2 uses) 38e, 38g, 38h, 77e (3 uses) 77j 77j 38c, 38d 38e, 77c - (2 uses) 77e (3 uses) 77g

TABLE X - Continued			
Failure Mode (in order of frequency of occurrence)	Corrective Action	Aggregation of Elemental Mech. Functions	Failure Case Reference Numbers
4. Leakage (cont'd)	A. Improved Part (cont'd)	h) Liquid Switching	38e 77e (3 uses)
		i) Liquid Transferring	77c (2 uses), 77g
		j) Force Transmitting	38c,38d
	B. Change of Material	a) Motion Constraining	124a
		b) Coupling	124a
		c) Sliding	124a
		d) Motion Transmitting	124a
		e) Torque Transmitting	124a
	C. Supplemental Part	a) Contaminant Constraining	124b
		b) Liquid Constraining	77e,77g
		c) Motion Constraining	124a
		d) Coupling	124a
		e) Sealing	77e,124b
		f) Sliding	124a
		g) Pressure Supporting	77e,77g
		h) Liquid Switching	77e
		i) Liquid Transferring	77g
		j) Motion Transmitting	124a
		k) Torque Transmitting	124a
	D. Changed Dimensions	a) Protective Covering	99NA
		b) Sealing	99NA
	E. Relocated or Repositioned Part	a) Liquid Constraining	77g
		b) Pressure Supporting	77g
		c) Liquid Transferring	77g
	F. Changed Lubricant Type or Added Lubricant	a) Motion Constraining	124a (2 uses)
		b) Coupling	124a (2 uses)
		c) Sliding	124a (2 uses)
		d) Motion Transmitting	124a (2 uses)
		e) Torque Transmitting	124a (2 uses)

TABLE X - Continued			
Failure Mode (in order of frequency of occurrence)	Corrective Action	Aggregation of Elemental Mech. Functions	Failure Case Reference Numbers
5. Impact	A. Improved Part	a) Attaching	109a
		b) Motion Constraining	109a
		c) Latching	109a
		d) Limiting	109a
	B. Supplemental Part	a) Lighting	18
		b) Energy Transforming	18
	C. Changed Loading on Part	a) Lighting	18
		b) Energy Transforming	18
6. Corrosion	A. Change of Material	a) Protective Covering	121a,121b
		b) Shielding	121a,121b
	B. Applied Surface Coating	a) Protective Covering	121a,121b
		b) Shielding	121a,121b
		c) Stabilizing	9a
		d) Supporting	9a
		e) Force Transmitting	9a
7. Bonding Failure	A. Supplemental Part	a) Protective Covering	13c
		b) Sealing	13c
	B. Changed Dimensions	a) Protective Covering	99NA
		b) Sealing	99NA
8. Seizure	A. Changed Loading on Part	a) Sliding	29e
		b) Supporting	29e
		c) Force Transmitting	29e
		d) Torque Transmitting	29e
9. Surface Fatigue	A. Change of Material	a) Motion Constraining	124a
		b) Coupling	124a
		c) Sliding	124a
		d) Motion Transmitting	124a
		e) Torque Transmitting	124a
	B. Supplemental Part	a) Motion Constraining	124a
		b) Coupling	124a
		c) Sliding	124a
		d) Motion Transmitting	124a
		e) Torque Transmitting	124a

TABLE X - Continued

Failure Mode (in order of frequency of occurrence)	Corrective Action	Aggregation of Elemental Mech. Functions	Failure Case Reference Numbers
9. Surface Fatigue (Cont'd)	C. Applied Surface Coating	a) Supporting	9a
	D. Changed Mechanism of Operation	a) Attaching	3c
		b) Motion Constraining	3c
		c) Friction Reducing	3c
		d) Rolling	3c
		e) Supporting	3c
	E. Changed Lubrication Type or Added Lubricant	a) Motion Constraining	124a (2 uses)
		b) Coupling	124a (2 uses)
		c) Sliding	124a (2 uses)
		d) Motion Transmitting	124a (2 uses)
		e) Torque Transmitting	124a (2 uses)
10. Galling	A. Supplemental Part	a) Limiting	177a,177b
		b) Sliding	177a,177b
		c) Torque Transmitting	177a,177b
11. Scoring	A. Change of Material	a) Protective Covering	2a
		b) Shielding	2a
		c) Light Transmitting	2a
		d) Viewing	2a
	B. Applied Surface Coating	a) Protective Covering	2a
		b) Shielding	2a,8a
		c) Sliding	8a
		d) Light Transmitting	2a
		e) Viewing	2a
12. Change in Material Properties	A. Change of Material	a) Contaminant Constraining	60b
		b) Sealing	60b
13. Erosion	A. Change of Material	a) Protective Covering	121a,121b
		b) Shielding	121a,121b

TABLE X - Continued

Failure Mode (in order of frequency of occurrence)	Corrective Action	Aggregation of Elemental Mech. Functions	Failure Case Reference Numbers
13. Erosion (cont'd)	B. Applied Surface Coating	a) Protective Covering	121a,121b
		b) Shielding	121a,121b
14. Fretting-Fatigue	A. Applied Surface Coating	a) Linking	261
		b) Supporting	261
		c) Force Transmitting	261
15. Imbalance	A. Changed to Correct Part	a) Guiding	51f
		b) Stabilizing	51f
16. Stress Rupture	A. Change of Material	a) Protective Action	2a
		b) Shielding	2a
		c) Light Transmitting	2a
		d) Viewing	2a
17. Improper Dimension	A. Adjusted Part	a) Force Maintaining	95b
		b) Position Restoring	95b
		c) Stabilizing	95b
18. Buckling	A. Change of Material	a) Protective Covering	121a
		b) Shielding	121a
19. Corrosion-Fatigue	A. Applied Surface Coating	a) Stabilizing	9a
		b) Supporting	9a
		c) Force Transmitting	9a
20. Unknown	A. Improved Part	a) Contaminant Constraining	77d
		b) Filtering	77d
		c) Pressure Increasing	38f
		d) Movable Lighting	132,154
		e) Pumping	38f
		f) Pressure Supporting	38f
		g) Liquid Transferring	38f
		h) Energy Transforming	132,154
	B. Supplemental Part	a) Contaminant Constraining	77d
		b) Filtering	77d
	C. Changed Mechanism of Operation	a) Attaching	259b
		b) Liquid Constraining	259b
		c) Disconnecting	259b
		d) Sealing	259b
		e) Switching	259b

TABLE X - Continued			
Failure Mode (in order of frequency of occurrence)	Corrective Action	Aggregation of Elemental Mech. Functions	Failure Case Reference Numbers
20. Unknown (Cont'd)	D. Eliminated Part	a) Contaminant Constraining	77d
		b) Filtering	77d

Of the 40 failure modes associated with the failure-experience matrix, a total of 32 were observed at least once among the failure case histories examined. Table X indicates that of the 32 observed failure modes only 19 were addressed by a corrective action which resulted in a documented improvement in failure resistance. The observation that 13 of the active failure modes were never addressed by a corrective action with documented improvement indicates both a need for better documentation and a need to reevaluate the consequences of these failure modes. The 13 failure modes requiring further attention include elastic deformation, yielding, brittle fracture, brinelling, creep, fretting-wear, impact-fatigue, delamination, lubrication failure, imbalance, electrochemical overheating, clogged filter, and electrical failures.

In studying the results of Table X, it appears that the three most frequently used corrective actions with documented improvement in failure resistance are (1) change of material, (2) surface coatings, and (3) use of a supplemental part. These three corrective actions were successfully used for a rather broad class of failure modes. Of the three, the use of surface coatings probably has the greatest potential for broad application to a variety of different failure modes including wear, fatigue, corrosion, surface fatigue, scoring, erosion, fretting-fatigue, corrosion-fatigue, and perhaps others. To reinforce this observation, which is based on the failure case histories examined, it was noted in talking with AVSCOM personnel at the USAARADMAC facility near Corpus Christi, Texas, that the use of surface coatings is also frequently employed in repair or product improvement procedures at that installation, often with good success. It is interesting to note, however, that there are only two information cells in Table IX which involve surface coating as a corrective action. This probably indicates that there are many cases in which surface coatings could have been effectively used as a corrective action but, for some reason, were not utilized.

ANALYSIS OF DATA FOR WHICH THE CORRECTIVE ACTIONS RESULTED IN NO IMPROVEMENT

It is often possible to find useful information in results which appear to be negative. For this reason, all of the data for corrective actions

which resulted in no improvement in failure resistance were carefully examined. This effort is summarized in Table XI.

TABLE XI. CORRECTIVE ACTIONS WHICH RESULTED IN AT LEAST TWO CASES WITH NO IMPROVEMENT IN FAILURE RESISTANCE ASSOCIATED WITH SPECIFIED FAILURE MODE

Failure Mode	Corrective Action	No. of Cases
1. Wear	A. Improved Part	11
	B. Direct Replacement	51
	C. Change of Material	4
	D. Improved Instructions to Field Personnel	2
	E. Made Parts Interchangeable	2
2. Ductile Rupture	A. Improved Part	6
	B. Direct Replacement	41
	C. Change of Material	3
	D. Repaired	6
3. Fatigue	A. Improved Part	3
	B. Direct Replacement	30
	C. Repaired	11
	D. Improved Instructions to Field Personnel	2
4. Leakage	A. Improved Part	8
	B. Direct Replacement	43
	C. Change of Material	6
	D. Supplemental Part	2
	E. Changed Dimensions	2
	F. Repaired	3
5. Yielding	A. Improved Part	5
	B. Direct Replacement	20
	C. Repaired	8
6. Impact	A. Improved Part	3
	B. Direct Replacement	23
	C. Repaired	5
7. Corrosion	A. Improved Part	3
	B. Direct Replacement	15
	C. Repaired	5

TABLE XI - Continued		
Failure Mode	Corrective Action	No. of Cases
8. Bonding Failure	A. Direct Replacement	11
	B. Supplemental Part	4
	C. Repaired	9
9. Seizure	A. Direct Replacement	9
	B. Supplemental Part	4
10. Surface Fatigue	A. Improved Part	4
	B. Direct Replacement	7
11. Galling	A. Direct Replacement	4
12. Scoring	A. Direct Replacement	4
13. Change in Material Properties	A. Direct Replacement	8
14. Erosion	A. Direct Replacement	3
15. Elastic Deformation	A. Direct Replacement	3
16. Fretting-Corrosion	A. Direct Replacement	3
17. Brittle Fracture	A. Direct Replacement	4
18. Stress Rupture	A. Direct Replacement	3
19. Fretting-Wear	A. Direct Replacement	2
20. Delamination	A. Direct Replacement	3
21. Clogged Filter	A. Direct Replacement	2
22. Unknown	A. Direct Replacement	16

It may be observed that "direct replacement" and "improved part" are the more frequent unsuccessful corrective actions employed. Direct replacement involves installation of a new part with the same probability of

failure, so that no improvement would be expected. Lack of success in improving failure resistance by using the "improved part" corrective action may be related to the fact that virtually no documentation was available on the details of improvement for parts in this category. The lack of documentation may indicate that the "improvement" was poorly defined or speculative, and therefore the chances of success were poor from the start. It may also be observed from Table XI that "Repair" as a corrective action frequently results in no improvement. Unfortunately, the documentation needed to more completely analyze these unsuccessful corrective actions was not available for this study.

DEVELOPMENT OF ACCELERATED T ΙING PROCEDURE FOR PREDICTION OF FAILURE BY WEAR

Based on the results of Table I, wear is the most frequently occurring failure mode observed in this study of over 500 documented helicopter component failures. Wear may be defined as the undesired cumulative change in dimensions brought about by the gradual removal of discrete particles from a surface due to mechanical action. Corrosion often interacts with the wear process to change the character of the surfaces or wear particles through reaction with the environment. It is only in the past decade that the state-of-the-art knowledge in wear research has progressed to the point that some success has been achieved in making quantitative predictions of wear. Such predictions are complicated by the fact that there are at least four major subcategories of wear: (1) adhesive wear, (2) abrasive wear, (3) corrosive wear, and (4) surface-fatigue wear [4][1]. In addition to these, fretting-wear is also an important wear process. Each type of wear proceeds by a distinctly different physical process and must be considered separately. However, the various subcategories may combine their influence either by shifting from one type of wear to another or by the simultaneous action of two or more different types of wear.

While progress has been made in recent years in developing quantitative wear models, very little effort has been directed toward the study of accelerated wear or fretting wear testing. Wear testing of components designed for long life is both expensive and time-consuming. The development of a reliable accelerated wear testing technique would represent a significant advancement in wear life prediction. Since very little effort has been directed toward the study of accelerated wear testing (in spite of the first rank importance of wear as a failure mode), major advances in predictive techniques might reasonably be expected from a well-planned accelerated-wear testing program.

Three methods of accelerated testing have been employed with some success in other fields and for other failure modes. The first method is applicable to components which operate cyclically. If the number of cycles to failure is not affected by cycling rate within a certain frequency range, then the cycling rate can be successfully increased to produce failure in a shorter time without changing the failure characteristics of the component. This technique is sometimes used in accelerated fatigue testing.

The second method may be used when a good mathematical model of the physical phenomenon is known in terms of its significant parameters and constants that may be evaluated experimentally. This method is sometimes used in accelerated creep or stress rupture testing.

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[1] Numbers in brackets designate references at end of report.

The third method involves the use of a linear cumulative damage model, similar to the widely used Palmgren-Miner cumulative fatigue damage model [4], which allows life prediction based on accelerated testing, without a detailed knowledge of the governing physical phenomenon and without an explicit mathematical model. This method has been used with some success [5] in accelerated life testing of several common items, including light bulbs, electric hand drills, electric motors, and bearing balls.

The accelerated wear testing procedure proposed here would capitalize upon all three accelerated testing methods. The procedure, described in detail in the following paragraphs, must ultimately involve: (1) performing statistically significant accelerated life tests, (2) making life predictions by the three methods described above, (3) performing statistically significant normal life tests, (4) correlation of results, and (5) evaluation of models and methods.

WEAR MODELS AND TESTING METHODS

Extensive review of the wear literature indicates that the most useful wear models are probably the following three. For adhesive wear [6]

$$d_w = k_w p_m L_s \quad \text{for } p_m < \sigma_{yp} \qquad \text{unstable galling and seizure for } p_m \geq \sigma_{yp} \tag{1}$$

where d_w is mean depth of the wear, p_m is mean nominal contact pressure, L_s is distance of sliding, σ_{yp} is the yield point strength of the material and k_w is an adhesive wear constant to be experimentally evaluated.

For abrasive wear [7]

$$d_{abr} = k_{abr} p_m L_s \tag{2}$$

where the terms are the same as above except k_{abr} is an abrasive wear constant.

For "zero" wear, defined to be wear of such small magnitude that the wear depth is the order of one-half the peak-to-peak surface finish dimension [8],

$$N = 2 \times 10^3 \left[\frac{\gamma_r \tau_{yp}}{\tau_{max}}\right]^9 \tag{3}$$

where N is the maximum number of passes for zero wear, τ_{yp} is the shear yield point of the material at the surface, τ_{max} is the maximum shearing stress in the vicinity of the surface due to both normal and friction

forces, and γ_r is an experimental constant.

These three models will be useful in evaluating the first and second accelerated testing methods described above.

To examine the use of the third testing method it is necessary to develop the concept of generalized cumulative damage. The coined word "stressor" will be used to refer to any generalized stress-like quantity that may be varied to accelerate a life test. For example, temperature, load and environment are all stressors. The generalized linear cumulative damage relationship then states that, for a specified failure mode, if the component life is L_1 at stressor level S_1, and the life is L_2 at stressor level S_2, then if the component is subjected to operation at stressor level S_1 for a time αL_1, it will have a remaining life at stressor S_2 of βL_2, where

$$\alpha + \beta = 1 \tag{4}$$

The validity of this relationship for the wear mode of failure remains to be established. Experimental verification will be indicated if two groups of specimens are tested as follows: Group I specimens are tested at stressor level S_1 for a time t_1 followed by testing at stressor level S_2, with failure observed after time t_2 at level S_2. Group II specimens then are first tested at stressor level S_2 for a time t_2 followed by testing at stressor level S_1, with failure observed after time t_3 at level S_1. If $t_3 = t_1$, the hypothesis is verified for this combination of conditions. Testing over a suitable range of stressor levels in various combinations would verify the model. It has been shown that for many types of failure this linear model seems to hold with reasonable accuracy [4].

If the model is verified, then accelerated life testing consists of running specimens first at a high stressor level, S_{hi}, until failure occurs. Such a failure point is shown as "A" in Figure 102. Next, specimens are run at normal operating stressor level S_{op} for a fraction α of the operating life time and then tested to failure at S_{hi}. This failure point is shown as "C" in Figure 102. Connecting the two points A and C with a straight line, and extrapolating the line to the horizontal axis, gives the life prediction for full operation at S_{op} only. This predicted life is indicated as point "B" in Figure 102. Since most of the testing time is at the accelerated stressor level, the total test time is reduced significantly.

For example, if life L_{hi} at the higher stressor level is 10 per cent of life L_{op} at the operating stressor level, and test time for point C at the operating stressor level is arbitrarily selected as 10 per cent of L_{op}, the total testing time to produce both of the data points A and C is $0.29\ L_{op}$. This includes $0.10\ L_{op}$ at S_{hi} for point A plus $0.10\ L_{op}$ at S_{op} followed by $0.90(0.10\ L_{op})$ at S_{hi} for point C. Thus, the test time has been accelerated by approximately a factor of four, and since the

tests at point A could probably be run simultaneously with the tests at point C, the effective test-time acceleration factor would exceed five.

SPECIMEN SELECTION

The criteria for selection of a suitable test specimen include the need for simplicity, compactness, economy, ease of controlling and measuring forces and motions, potential for application of coatings and platings to the wearing surface, and a desire to use a currently troublesome helicopter component so that laboratory results might be directly applicable to a specific problem area, as well as providing data for developing generalized predictive methods and accelerated testing techniques. The cyclic servo support bearing seems to meet all of these criteria relatively well.

The cyclic servo support bearing consists of a double-truncated sphere supported by two rings with spherical mating surfaces, as shown in Figure 103. The spherical element has a cylindrical hole through it for securing it to the servo actuator rod.

In actual helicopter operation the input load is cyclic, has a maximum amplitude of about 1800 pounds, and is applied along the axis of the bearing ball. The frequency of this loading is about 650 cycles per minute. The input motion consists of movement of the bearing ball axis through an arc of approximately $7\frac{1}{2}^{\circ}$, essentially in one plane. The servo and attached bearing ball are not constrained from small rotational motion about the bearing ball axis. In addition to the external loads on the bearing, there is a preload pressing the bearing rings against the ball.

Four loading and motion parameters could reasonably be varied in testing this bearing: load amplitude, load frequency, motion amplitude, and motion frequency. It is judged that changing the motion amplitude significantly might change the mechanism of failure, particularly if fretting is involved. The load frequency would be expected to have less effect than the load amplitude. Therefore, two series of tests would provide the desired information, one series using load amplitude as the variable stressor, and the other series using motion frequency as the variable stressor. In each series, all other parameters would be held constant at values consistent with actual "normal" operation.

SELECTION OF ACCELERATED STRESSOR RANGES

Values must be selected for load amplitude and motion frequency to provide a useful degree of acceleration without changing the failure mechanism. A reduction in life by a factor of approximately five is thought to be the minimum that would yield a significant savings in time. Larger acceleration factors would increase the chance of changing the

failure mechanism. Therefore, the initial stressor values should be selected to produce component lives of about one-fifth or less of their normal operating lifetimes. While such values cannot be accurately estimated for the cyclic servo support bearing to be tested, equations (1), (2) and (3) may be used to estimate initial values for the accelerated stressor levels.

For equations (1) and (2), the damage rate is directly proportional to load for fixed sliding velocity and constant material properties. This suggests that one accelerated test value for the load stressor should be about five times the normal load. The damage rate is also directly proportional to the frequency of motion for a fixed sliding distance per cycle. Thus the frequency stressor should also be about five times the normal operating frequency for accelerated testing.

In equation (3), the life for "zero wear" is inversely proportional to the ninth power of the maximum shearing stress at the wearing interface. If the bearing rings and bearing ball are closely matched, the stresses are approximately proportional to the load. Thus, to accelerate the test by a factor of five, the load stressor must be increased by a factor of $\sqrt[9]{5}$, or about 1.2. If the motion frequency is unchanged, this change in load should reduce the "zero wear" life by a factor of about five. If the load is maintained at the normal operating value, the life is inversely proportional to the frequency of motion, so the frequency stressor should be increased to five times the normal frequency to obtain the desired test acceleration. Based on the above estimates, it would be proposed to use load stressor magnitudes of about 1.2 and about 5 times the normal load with an intermediate magnitude arbitrarily selected between these two values. Thus, factors at 1.2, 2.5, and 5 times the normal load would be proposed for the three accelerated load stressor values.

For all wear models discussed, a factor of 5 seems appropriate for accelerated frequency testing. Arbitrarily selecting additional factors larger and smaller than 5, it would be proposed to use frequency accelerating factors of 2.5, 5.0, and 10.0.

DEFINITION OF FAILURE BY WEAR IN THE CYCLIC SERVO SUPPORT BEARING

For many failure modes, such as ductile rupture or fatigue, failure is well defined. For wear, however, the definition of exactly when failure occurs is more difficult. Bearings used in Army helicopters have specified limits for looseness (play) and roughness, but the cyclic servo support bearing can be adjusted to eliminate looseness, so a specified amount of play would not be sufficient to define failure.

One method of determining failure would be to periodically disassemble and inspect the bearing, using some measure of surface damage to the bearing ball and rings as the criteria for failure.

An alternative to complete disassembly would be to measure the force required to move the ball through a specified arc. Failure might then be defined by a specified combination of force and motion under an accurately controlled preload. This force might conceivably be measured without interrupting the testing of the bearing, and controls might be used that would automatically terminate the test when failure is reached. Selection of suitable criteria for failure would require examination of failed bearings and measurement of the friction force and motion characteristics for failed bearings.

TESTING MACHINE REQUIREMENTS

To perform the wear testing program, it would be necessary to design and construct suitable wear testing machines, since no "standard" machines exist. These devices should be versatile enough to provide all of the types of loadings and motions associated with the cyclic servo support bearing tests described above, and, where possible, additional features to accommodate other wear tests that might be of interest in the future. Ranges of loads and motions should exceed the requirements for testing the cyclic servo support bearings. Both unidirectional motion and oscillatory motion should be provided in the design if possible. Fixtures for mounting the specimens and maintaining proper preloads would be required, as would instrumentation and controls to measure and maintain proper loads and motions. Failure detection would be a necessary feature. Further, it would probably be necessary to construct multiple units to obtain statistically significant data in a reasonable period of time.

DEFINITION OF AN ACCELERATED WEAR TESTING PROGRAM

To investigate the validity and potential of the models and methods defined by equations (1) through (4), the following series of wear tests could be utilized. In each test it would be necessary to control, calculate, or measure each of the following parameters:

(1) Amplitude of normal static or cyclic force between contacting surfaces.

(2) Frequency of normal static or cyclic force.

(3) Amplitude of relative cyclic motion.

(4) Frequency of relative cyclic motion.

(5) Sliding distance and velocity.

(6) Coefficient of friction.

(7) Maximum shearing stress in vicinity of surface, including frictional influence.

(8) Mean depth and volume of wear track.

(9) Tensile and shear yield strength of surface material.

(10) Hardness of surface material.

(11) Characteristic temperature.

(12) Environment, including lubricant or contaminant.

Of these parameters, two would be tentatively selected as stressors for accelerating the test. These are

(1) P = normal operational amplitude of axial load (approximately 1800 lb maximum)

(2) f_θ = normal operational frequency of angular motion of oscillating bearing axis (to be determined from service data)

Using the normal operational load amplitude as the stressor, the following two-step test series could be used. In these tests all parameters except P would be held constant at "normal" values.

TABLE XII. ACCELERATED WEAR TESTING PROGRAM USING OPERATIONAL LOAD AMPLITUDE AS THE STRESSOR

Series (a): Step I		Series (a): Step II	
Load amplitude and frequency	Duration of loading	Load amplitude and frequency	Duration of loading
P (static)	L_{Ps} (failure)	--	--
P @ 650 cpm	L_P (failure)	--	--
P " " "	0.25 L_P	5 P @ 650 cpm	till failure ($t_{0.25}$)
P " " "	0.50 L_P	5 P " " "	" " ($t_{0.50}$)
P " " "	0.75 L_P	5 P " " "	" " ($t_{0.75}$)

TABLE XII - Continued			
Series (a): Step I		Series (a): Step II	
Load amplitude and frequency	Duration of loading	Load amplitude and frequency	Duration of loading
5P @ 650 cpm	$t_{0.25}$	P @ 650 cpm	till failure
5P " " "	$t_{0.50}$	P " " "	" "
5P " " "	$t_{0.75}$	P " " "	" "
5P " " "	till failure	--	--
5P (static)	till failure	--	--
Series (b) - Identical to series (a), except using 2.5 P instead of 5.0 P.			
Series (c) - Identical to series (a), except using 1.2 P instead of 5.0 P.			

Using the normal operational frequency of angular motion of the oscillating bearing axis as the stressor, the following two-step test series would be proposed in which all parameters, except f_θ, would be held constant at "normal" values.

TABLE XIII. ACCELERATED WEAR TESTING PROGRAM USING OPERATIONAL FREQUENCY OF ANGULAR MOTION AS THE STRESSOR			
Series (d): Step I		Series (e): Step II	
Oscillating Motion Frequency	Duration of Oscillating Motion	Oscillating Motion Frequency	Duration of Oscillating Motion
f_θ	till failure[1] $L_{\theta s}$	--	--
f_θ	till failure[2] L_θ	--	--
f_θ	$0.25\ L_\theta$	$5\ f_\theta$	till failure ($t'_{0.25}$)

TABLE XIII - Continued			
Series (d): Step I		Series (e): Step II	
Oscillating Motion Frequency	Duration of Oscillating Motion	Oscillating Motion Frequency	Duration of Oscillating Motion
f_θ	$0.50\ L_\theta$	$5f_\theta$	till failure ($t'_{0.50}$)
f_θ	$0.75\ L_\theta$	$5f_\theta$	" " ($t'_{0.75}$)
$5f_\theta$	$t'_{0.25}$	f_θ	till failure
$5f_\theta$	$t'_{0.50}$	f_θ	" "
$5f_\theta$	$t'_{0.75}$	f_θ	" "
$5f_\theta$	till static failure	--	--
$5f_\theta$	till cyclic failure	--	--
Series (e) - Identical to series (d), except using 10 f_θ instead of 5.0 f_θ.			
Series (f) - Identical to series (d), except using 2.5 f_θ instead of 5.0 f_θ.			

[1] Under static application of P. This is same data as first item of series (a).

[2] Under cyclic application of P @ 650 CPM. This is same data as second item of series (a).

Exploratory testing could be conducted using three specimens for each condition in each test series specified. This would involve ten conditions for each of six series for a total of 180 test specimens. Final statistically significant data would require a minimum of twelve additional specimens at each of three sets of conditions in at least two of the series above for a total of at least 60 additional test specimens. Thus, a total of about 250 cyclic servo support bearings would be required for the testing program outlined. The time required to acquire the data would depend upon the design life of the bearing under operating load as well as the number of testing machines available. It is estimated that two to three years would be required to complete the testing program after the testing machines are designed and constructed. The potential improvement in wear prediction capability through accelerated testing is thought to justify such an investment of time and effort.

SUMMARY AND CONCLUSIONS

Of the 32 failure modes identified in studying more than 500 documented failures of helicopter components, the most frequently occurring failure mode was wear. In fact, wear and wear-related failures accounted for approximately one-half of all failures observed. Clearly, the "wear" failure mode should be studied intensively.

A survey of the technical literature indicates that while progress has been made in recent years in developing quantitative wear-prediction models, little effort has been directed toward the study of accelerated wear testing as a predictive tool. In view of the fact that wear testing of components designed for long life is both expensive and time-consuming, the development of a reliable accelerated wear testing technique would represent a significant advance in wear life prediction. The development of an accelerated wear testing technique is thought to be feasible based on the analyses of this investigation, and the bases for statistically testing the validity of the proposed technique are presented in an earlier section of this report.

The more frequently used corrective actions which resulted in demonstrated improvement, based on the results shown in Table X, include change of material, surface coatings, and use of a supplemental part. These three corrective actions were successfully used to improve resistance to a broad class of failure modes, including wear, fatigue, corrosion, surface fatigue, scoring, erosion, fretting-fatigue, and corrosion-fatigue. Of the three corrective actions noted above, the use of surface coatings is thought to have unique potential for wide application, especially in view of recent advances made in the technology of applying surface coatings. In fact, the use of appropriate surface coatings should not be reserved solely as a corrective action, but should probably be more fully exploited as a premeditated design specification.

Of the 32 active failure modes observed in this investigation, there were 13 failure modes that were never addressed by a corrective action with documented improvement. This observation may only reflect the need for better documentation, or it may indicate a need to carefully re-evaluate the failure modes and corrective actions involved. The 13 failure modes requiring further attention include elastic deformation, yielding, brittle fracture, brinelling, creep, fretting-wear, impact-fatigue, delamination, lubrication failure, imbalance, electrochemical overheating, clogged filter, and electrical failures.

The failure-experience matrix used in this study to organize and analyze the documented failure data proved to be an extremely valuable tool. Based on the data available in this study, however, the matrix was sparsely populated. To make the failure-experience matrix a more useful tool, it will be necessary to analyze and insert more data. Not only would data from Army helicopter component failures be useful, but data

from other aircraft, ground transportation vehicles, and even data from entirely different types of industrial and military applications would be appropriate. With proper computer-aided management of such an organized data-bank, the failure-experience matrix could become not only an important analytical technique but a powerful design tool as well. An engineer faced with the design of a critical component would only need to classify the intended function(s) of his component, enter the matrix with the function(s), and note the failure modes most likely to occur and corrective actions most likely to avert the failure. Likewise, a development or field service engineer, faced with a field failure, would only need to identify the active failure mode and classify the function of the part to enter the matrix and read out the corrective action most likely to solve the problem.

To fully exploit the future potential of the failure-experience matrix conceived in this investigation, it will be necessary to improve the documentation of mechanical failure histories, including identification of the basic failure modes, engineering evaluation of the problem and corrective actions proposed, when and how the corrective actions were implemented, and, especially, quantitative results of the corrective action in terms of failure statistics before and after implementation of the action. The major shortcoming of the failure-experience matrix as currently constituted is lack of quantitative information on the effectiveness of corrective actions. If such quantitative information could be secured for the case histories now in the matrix, the usefulness of the matrix would be greatly improved. Attempts to obtain such information have not yet been successful, but additional effort in this direction might be well spent. In any event, it is very important that future documentation include this essential information. Further, it would be very helpful if two-way failure accounting trails could be established on future documentation so that failure case histories could be traced forward or backward from any given important document in the chain.

Finally, it is important to note that the part that fails is not always the part that should get the corrective action. In this study a few cases were noted in which the failure resistance of one part was successfully improved by applying a corrective action to a different part. There may have been many other cases in which such a procedure would have been effective. This suggests the need for further study in the areas of failure sequence effects, identification of primary and secondary failures, and establishment of failure environment influence. Techniques for directing corrective actions toward primary causes rather than secondary effects should be improved. Combination of the useful results from these studies, together with the potential of a growing failure-experience matrix, should provide significant improvements in failure prevention, reliability and economy.

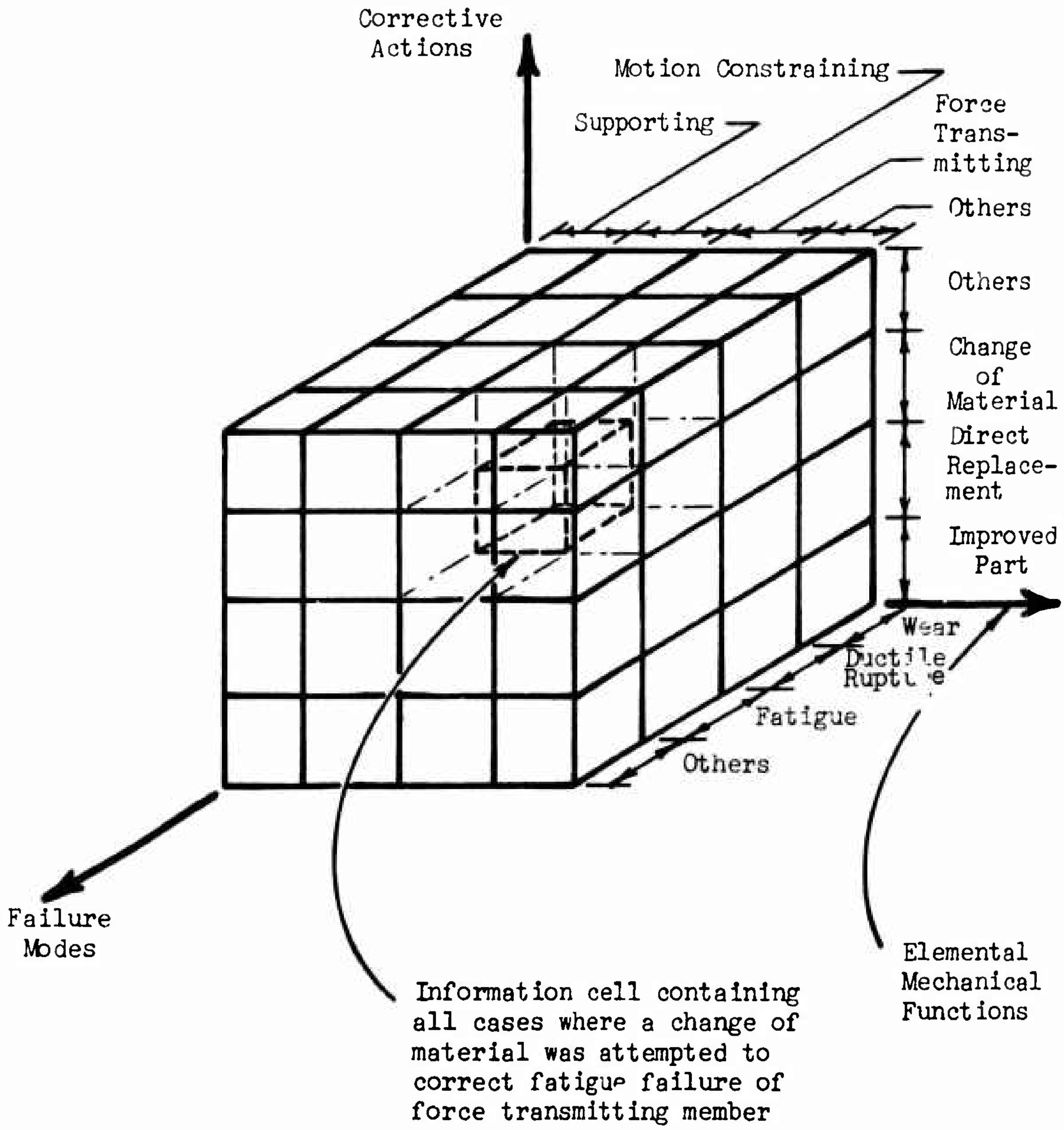


Figure 1. Illustration of a Portion of the Failure-Experience Matrix Used to Evaluate Documented Mechanical Failure Problems in U. S. Army Helicopters.

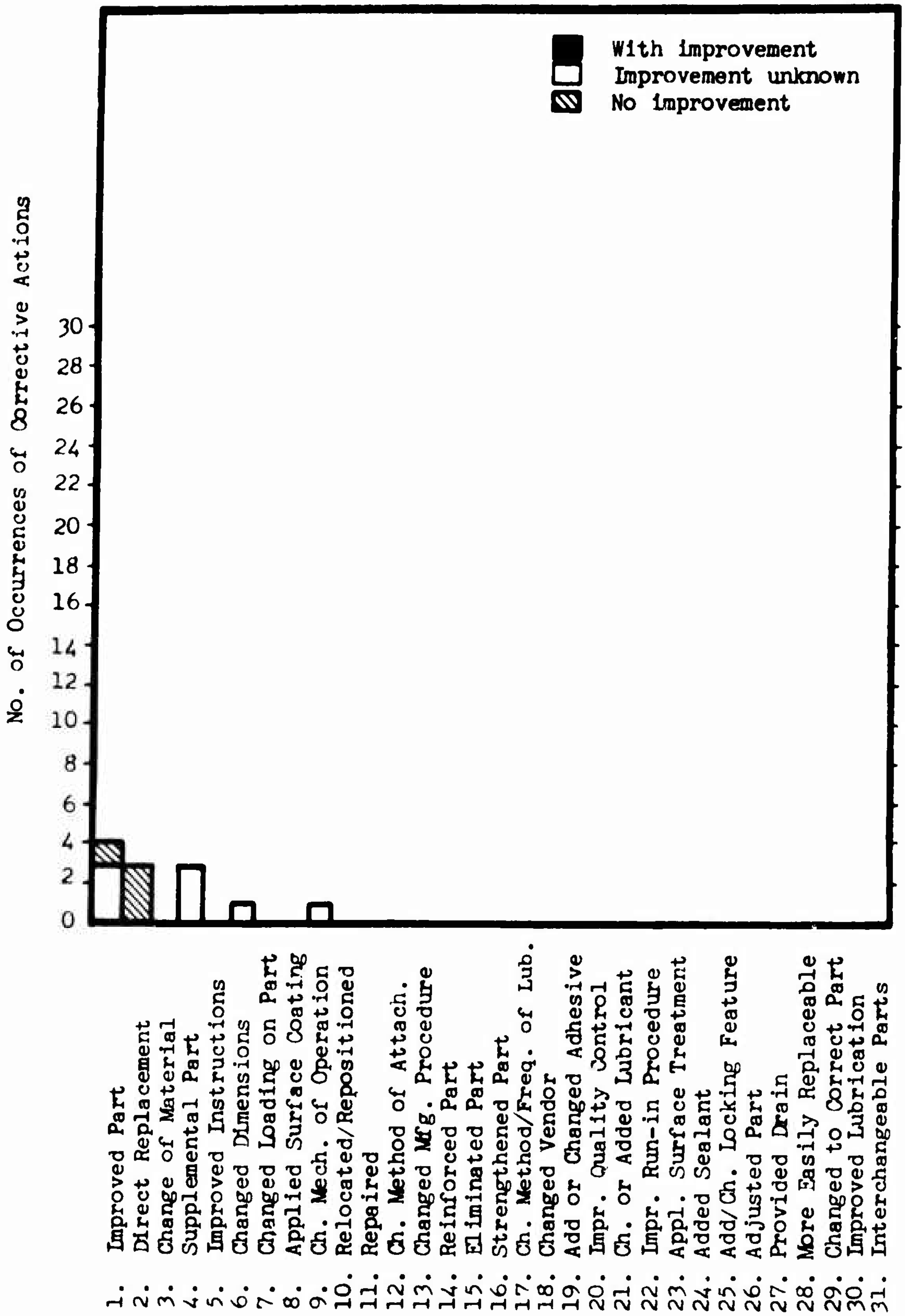


Figure 2. Frequency of Corrective Action Usage for Elastic Deformation Failure Mode - Series I.

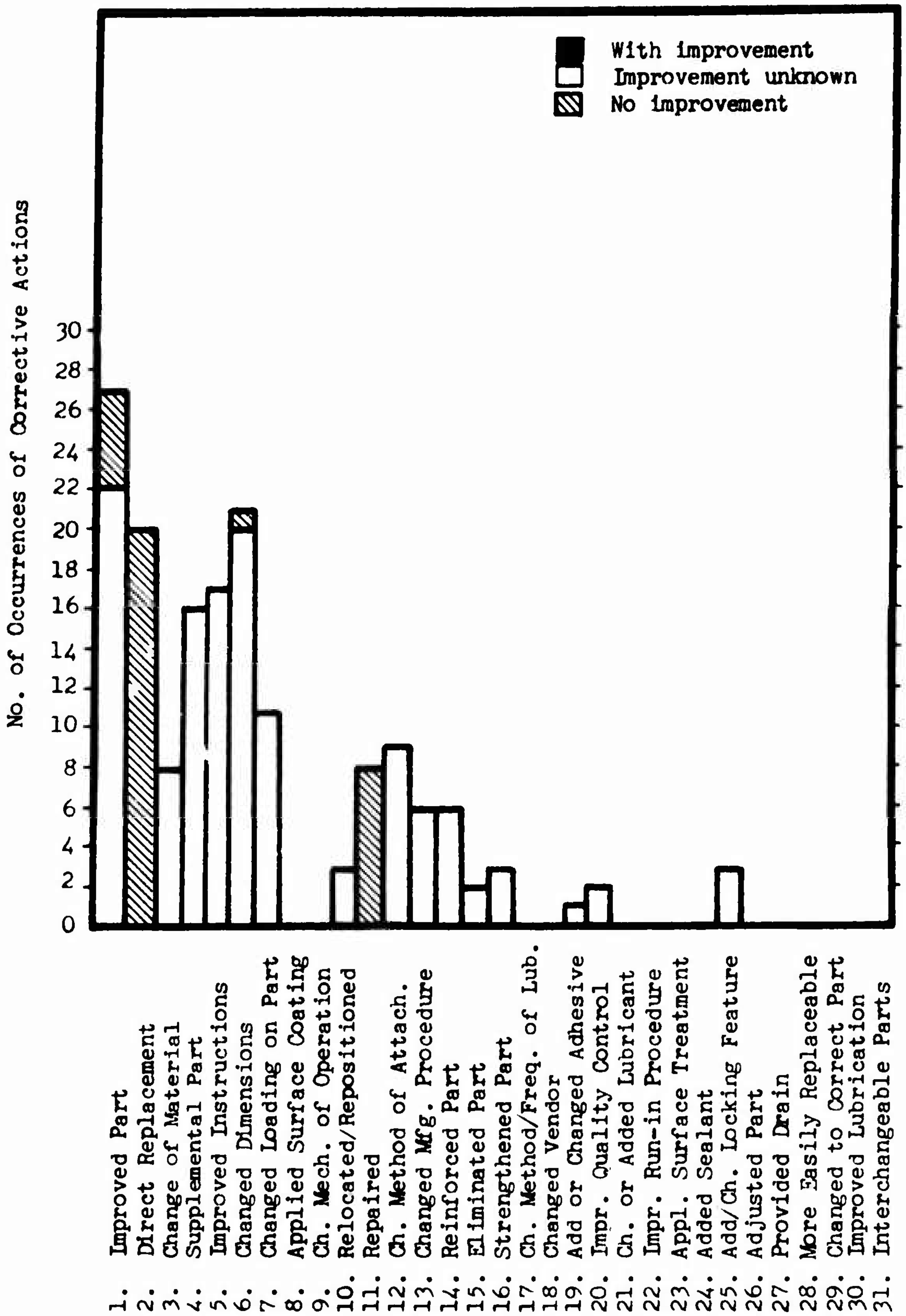


Figure 3. Frequency of Corrective Action Usage for Yielding Failure Mode - Series I.

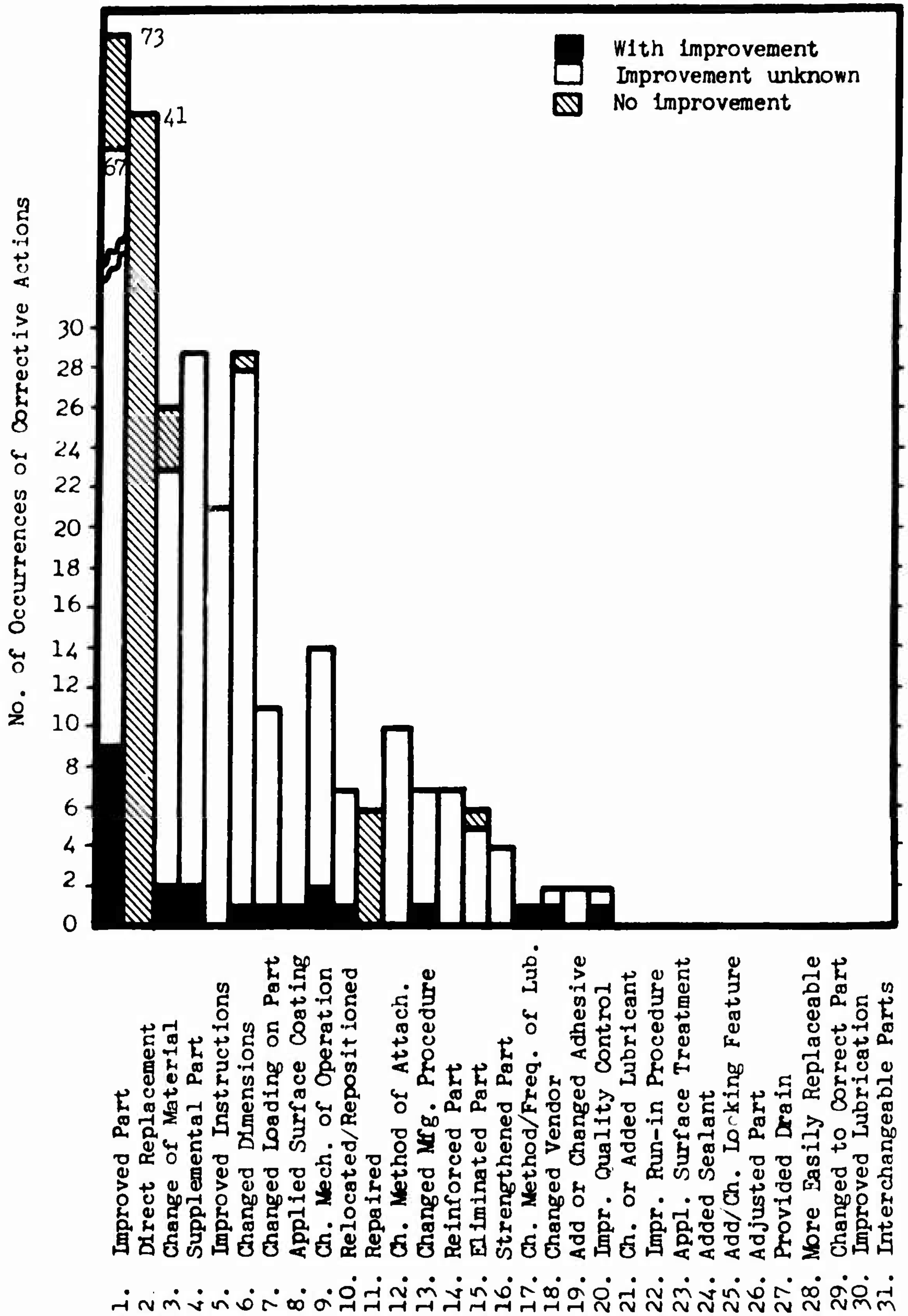


Figure 4. Frequency of Corrective Action Usage for Ductile Rupture Failure Mode - Series I.

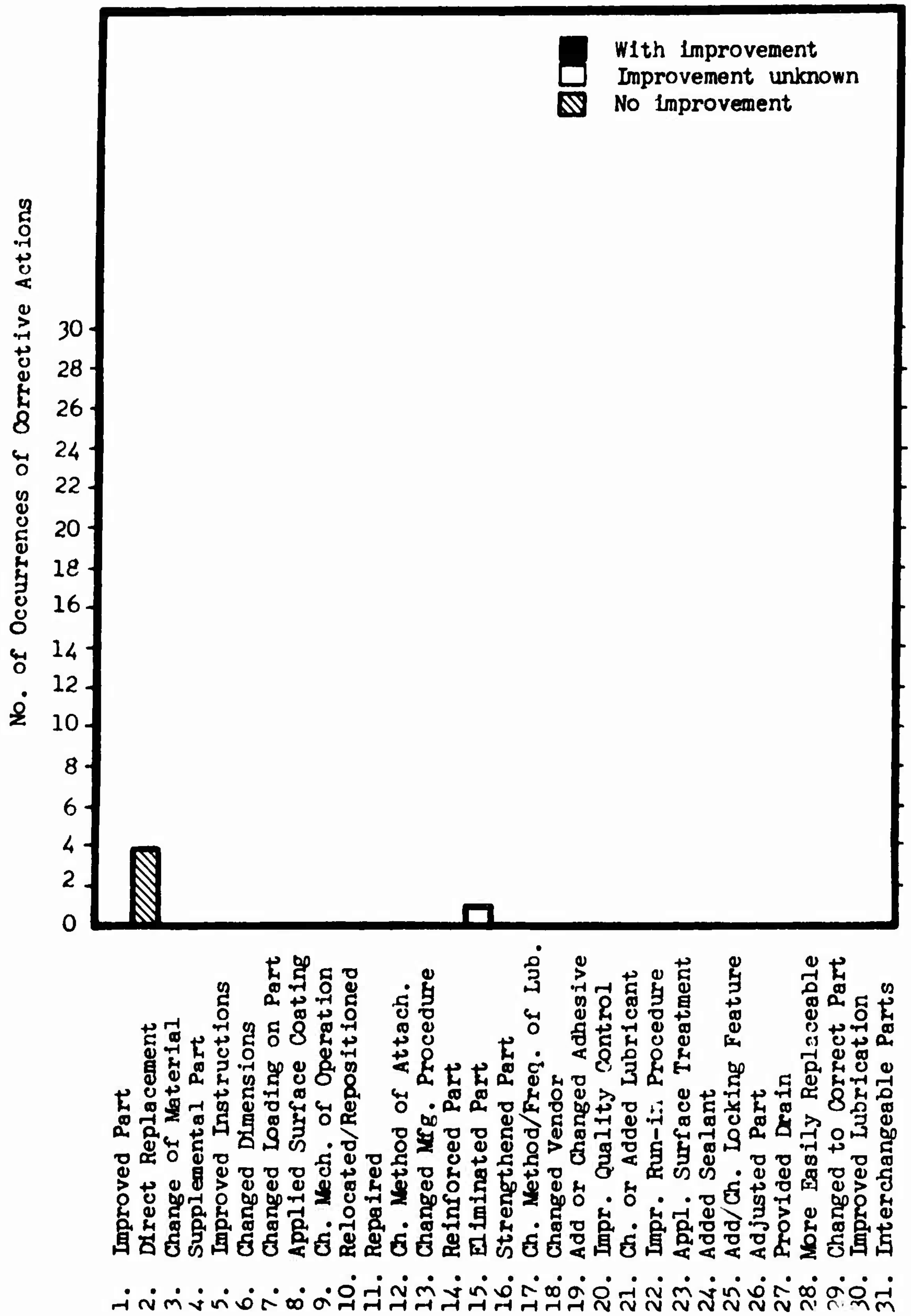


Figure 5. Frequency of Corrective Action Usage for
<u>Brittle Fracture</u> Failure Mode - Series I.

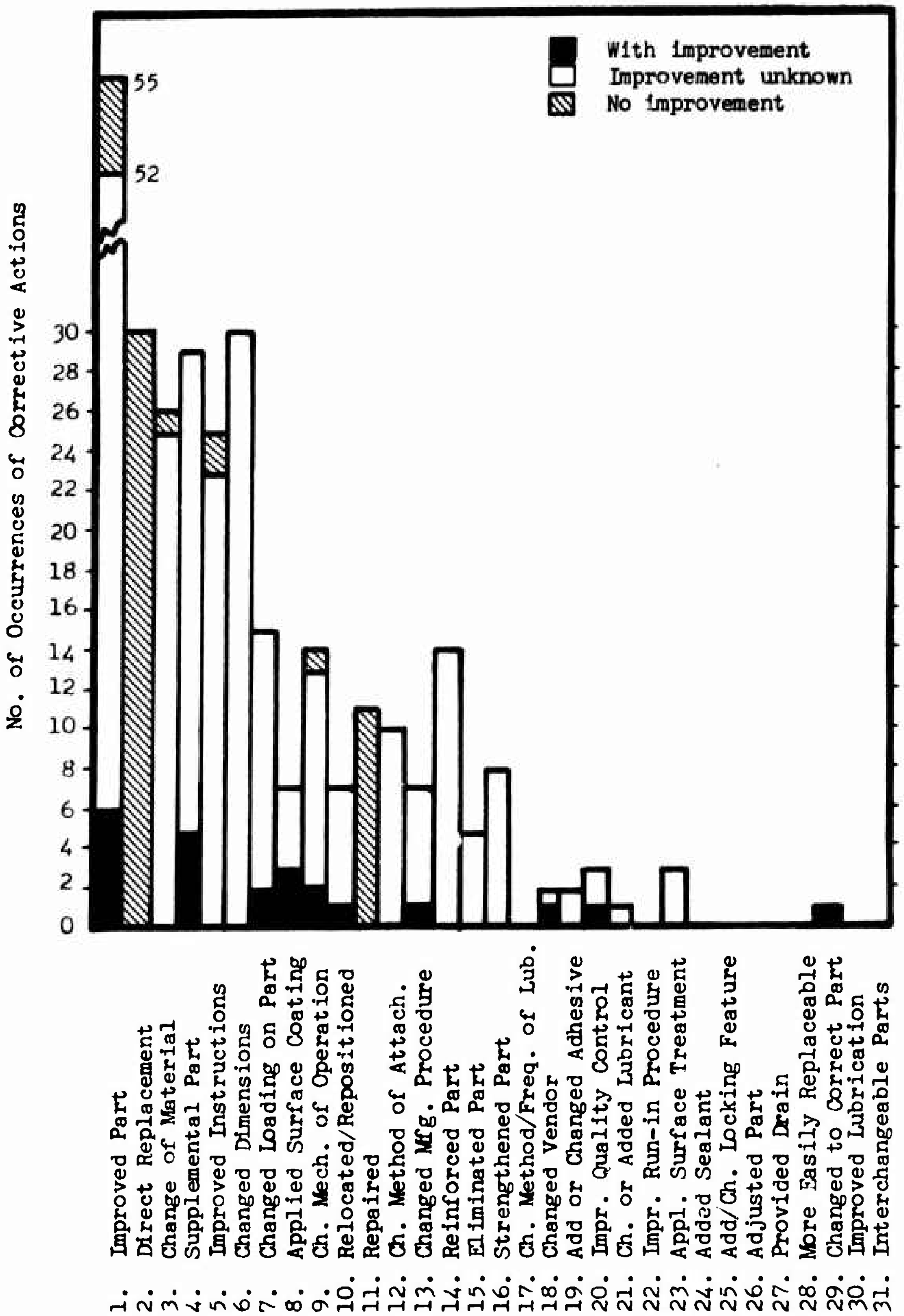


Figure 6. Frequency of Corrective Action Usage for <u>Fatigue</u> Failure Mode - Series I.

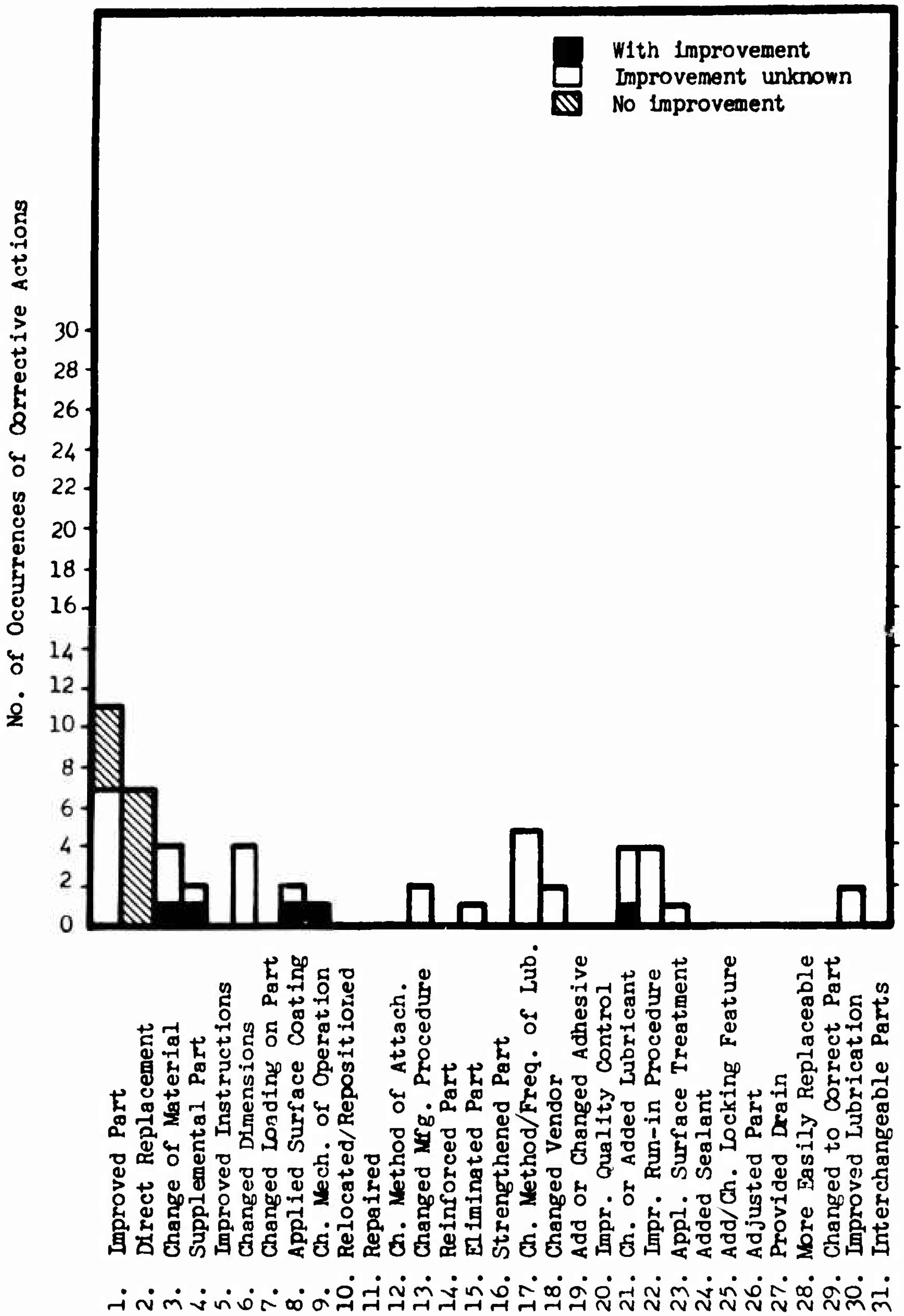


Figure 7. Frequency of Corrective Action Usage for <u>Surface Fatigue</u> Failure Mode - Series I.

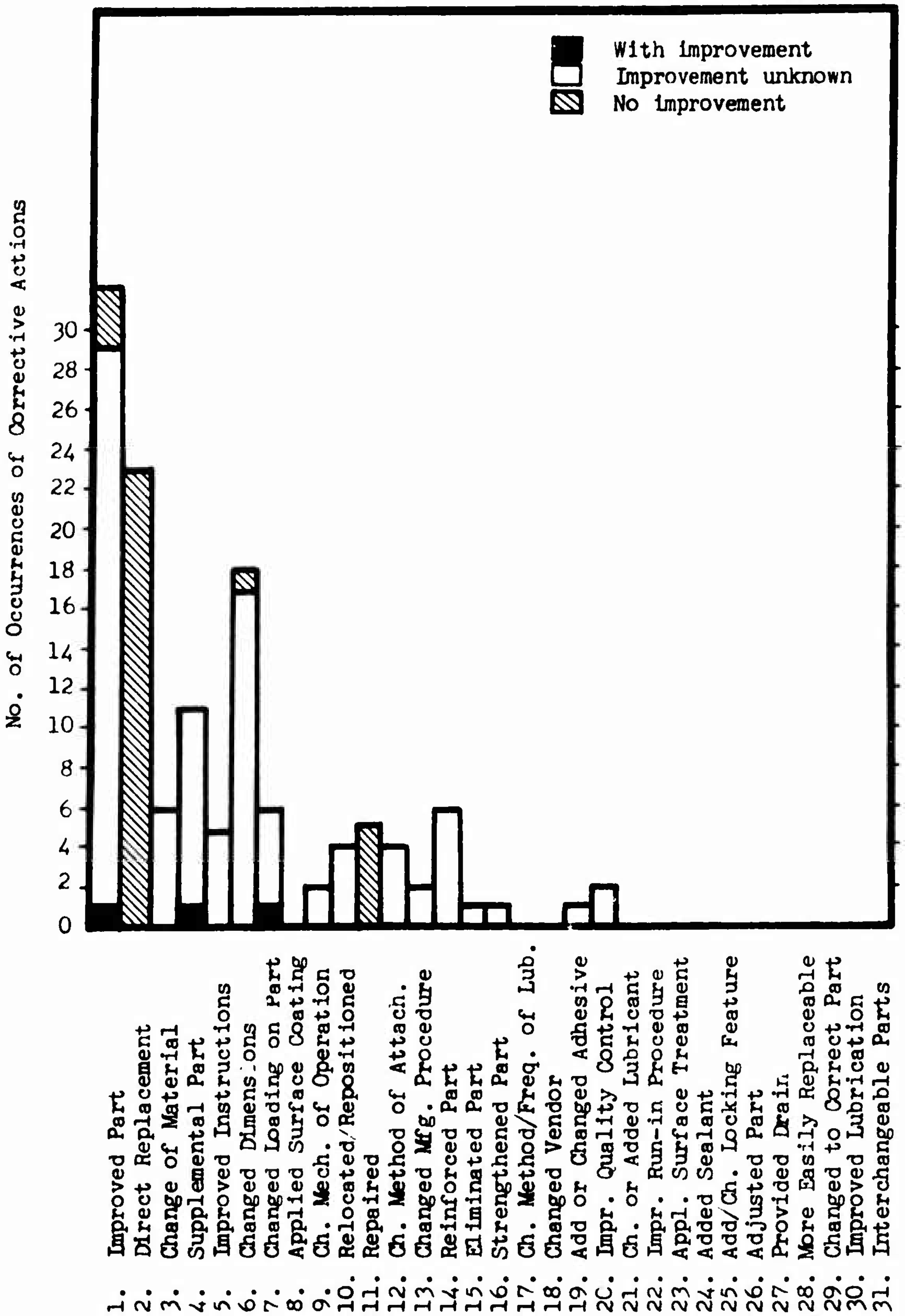


Figure 8. Frequency of Corrective Action Usage for Impact Failure Mode - Series I.

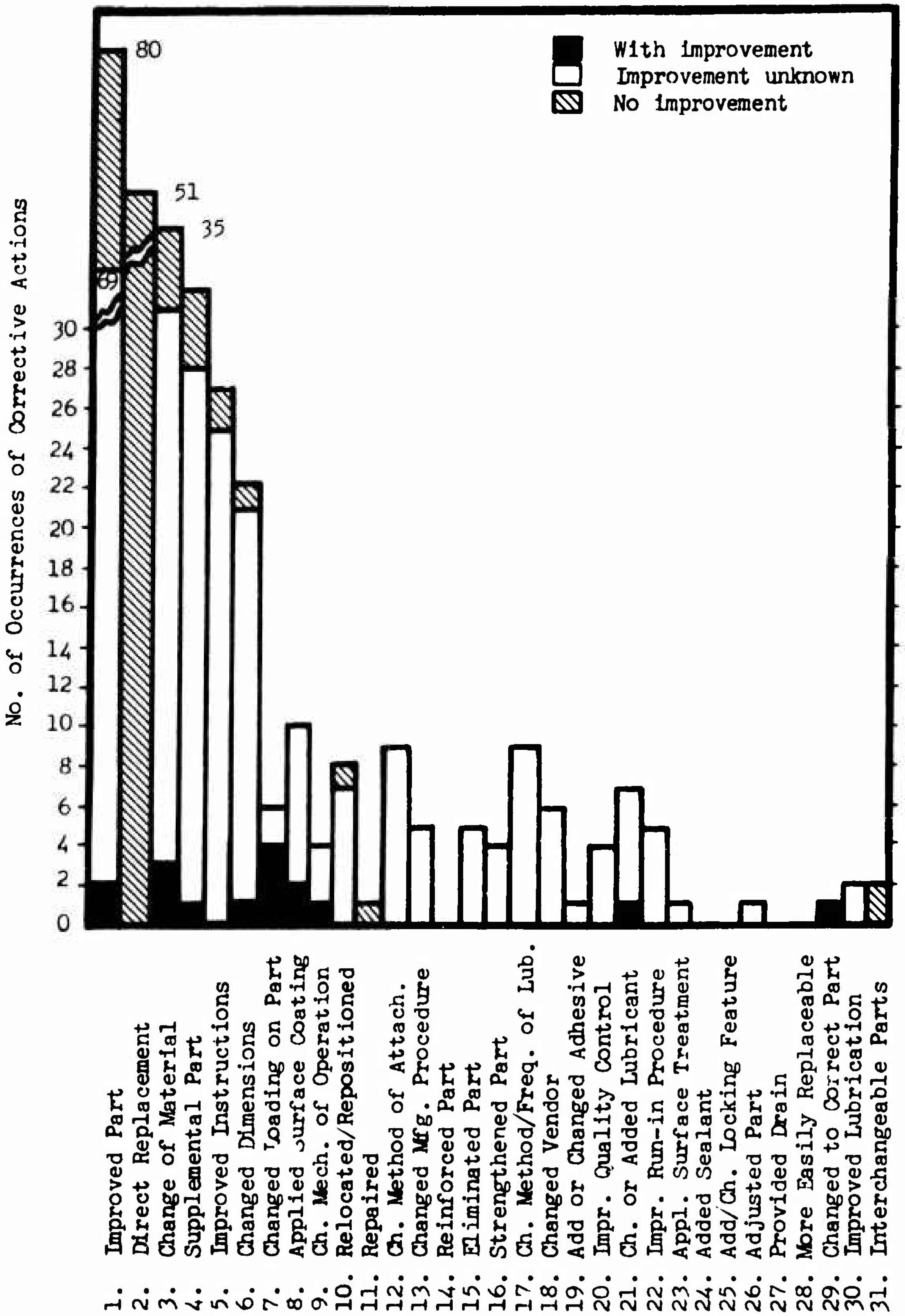


Figure 9. Frequency of Corrective Action Usage for <u>Wear</u> Failure Mode - Series I

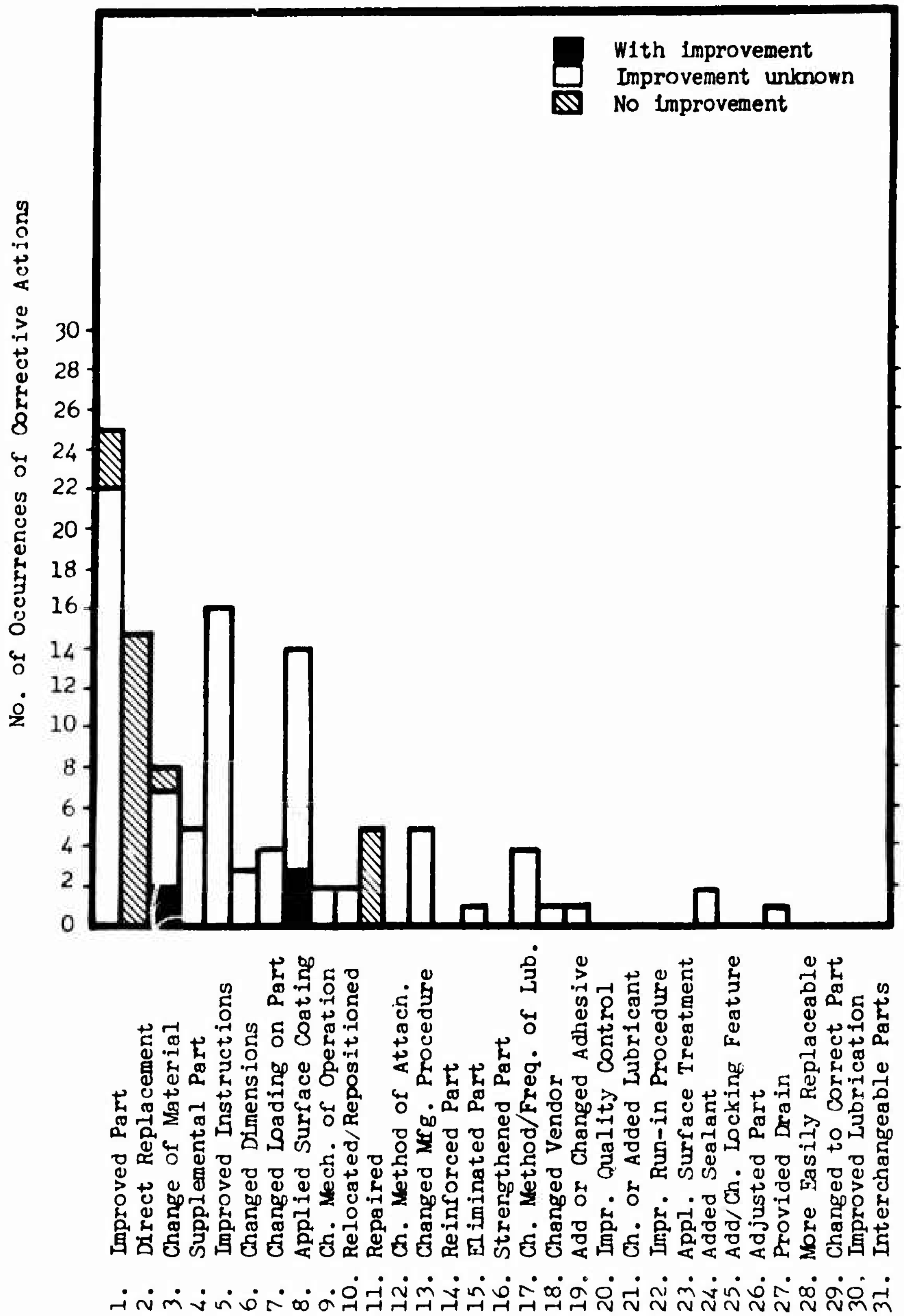


Figure 10. Frequency of Corrective Action Usage for Corrosion Failure Mode - Series I.

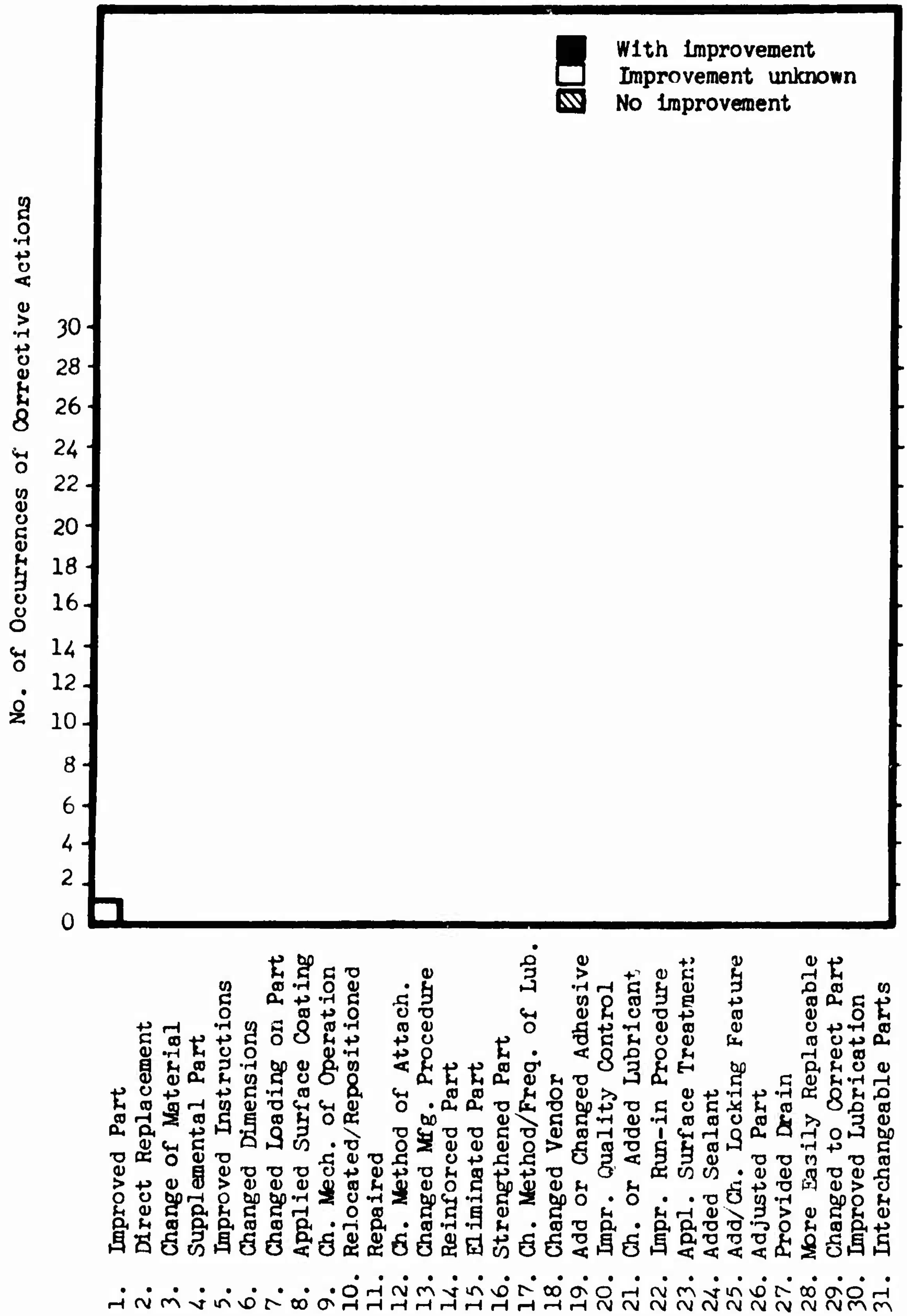


Figure 11. Frequency of Corrective Action Usage for <u>Brinelling</u> Failure Mode - Series I.

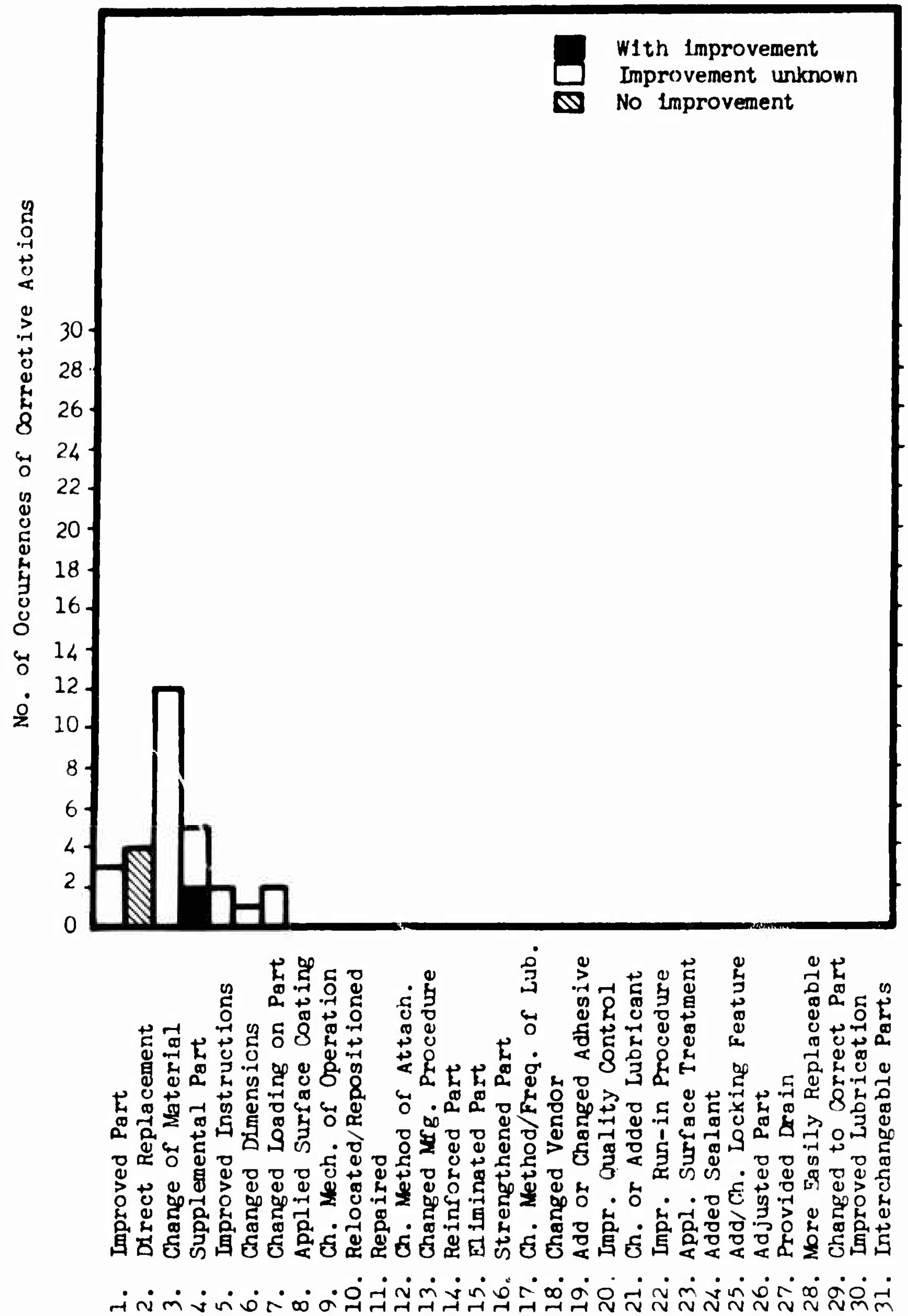


Figure 12. Frequency of Corrective Action Usage for Galling Failure Mode -- Series I.

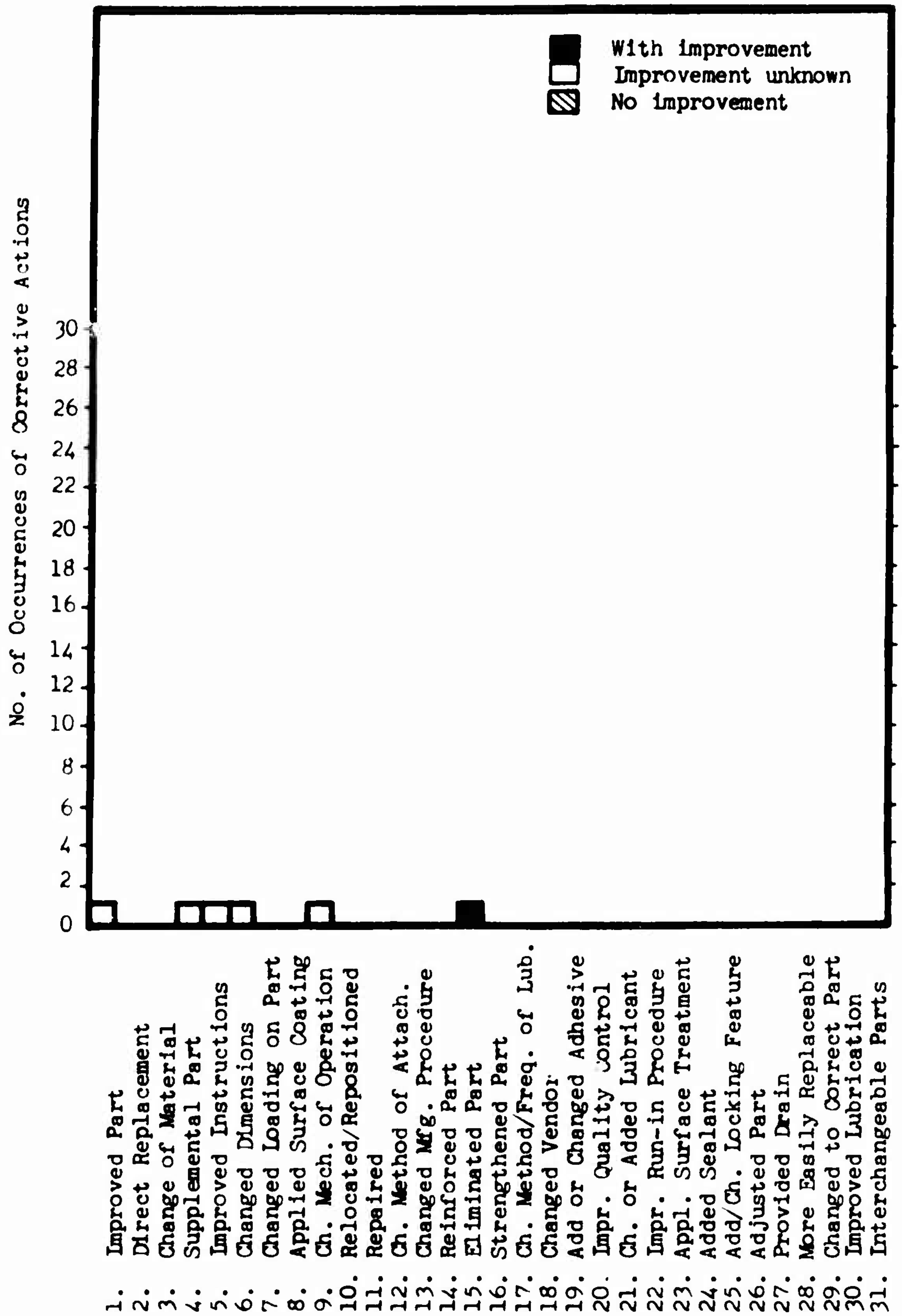


Figure 13. Frequency of Corrective Action Usage for Creep Failure Mode - Series I.

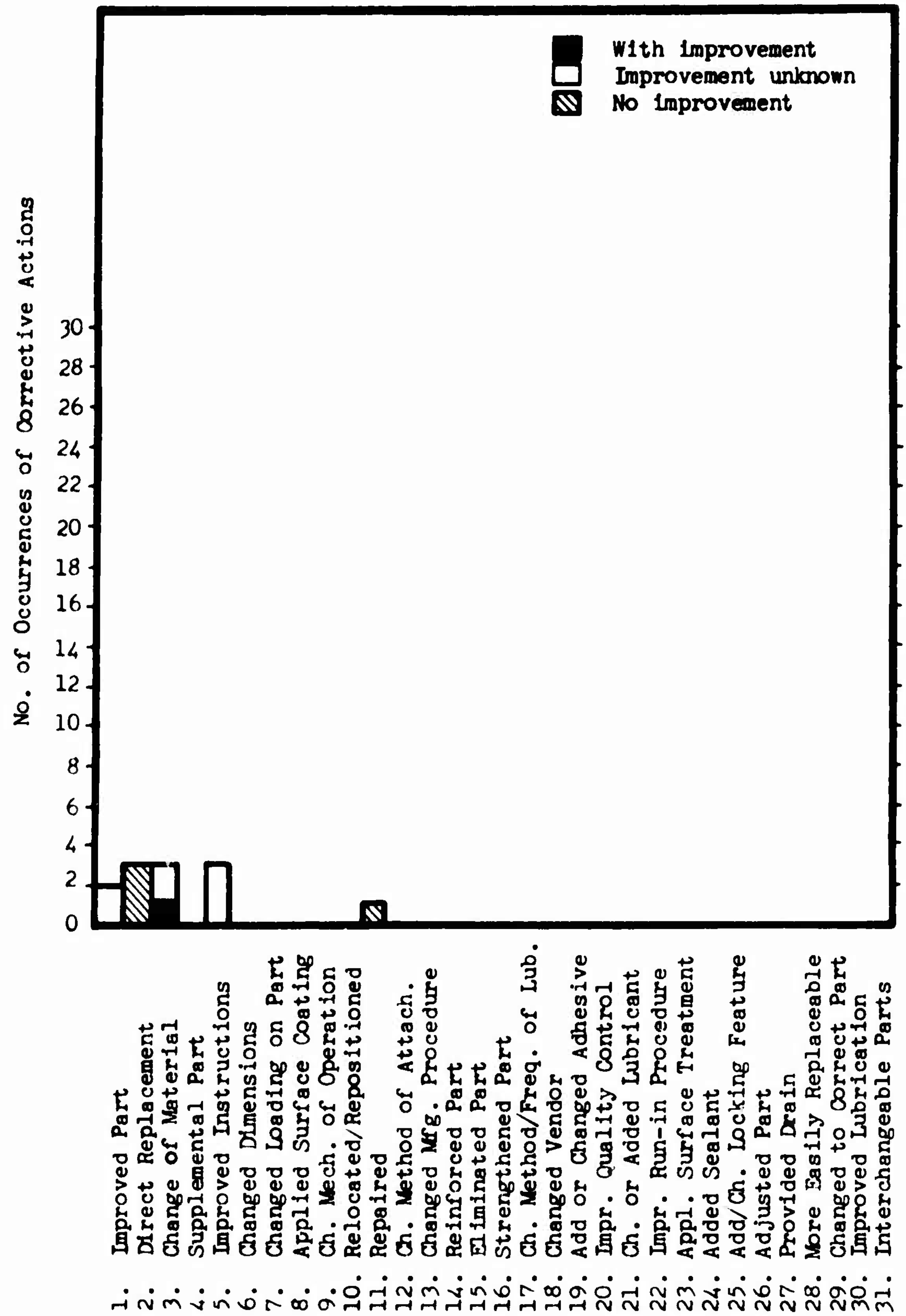


Figure 14. Frequency of Corrective Action Usage for Stress Rupture Failure Mode - Series I.

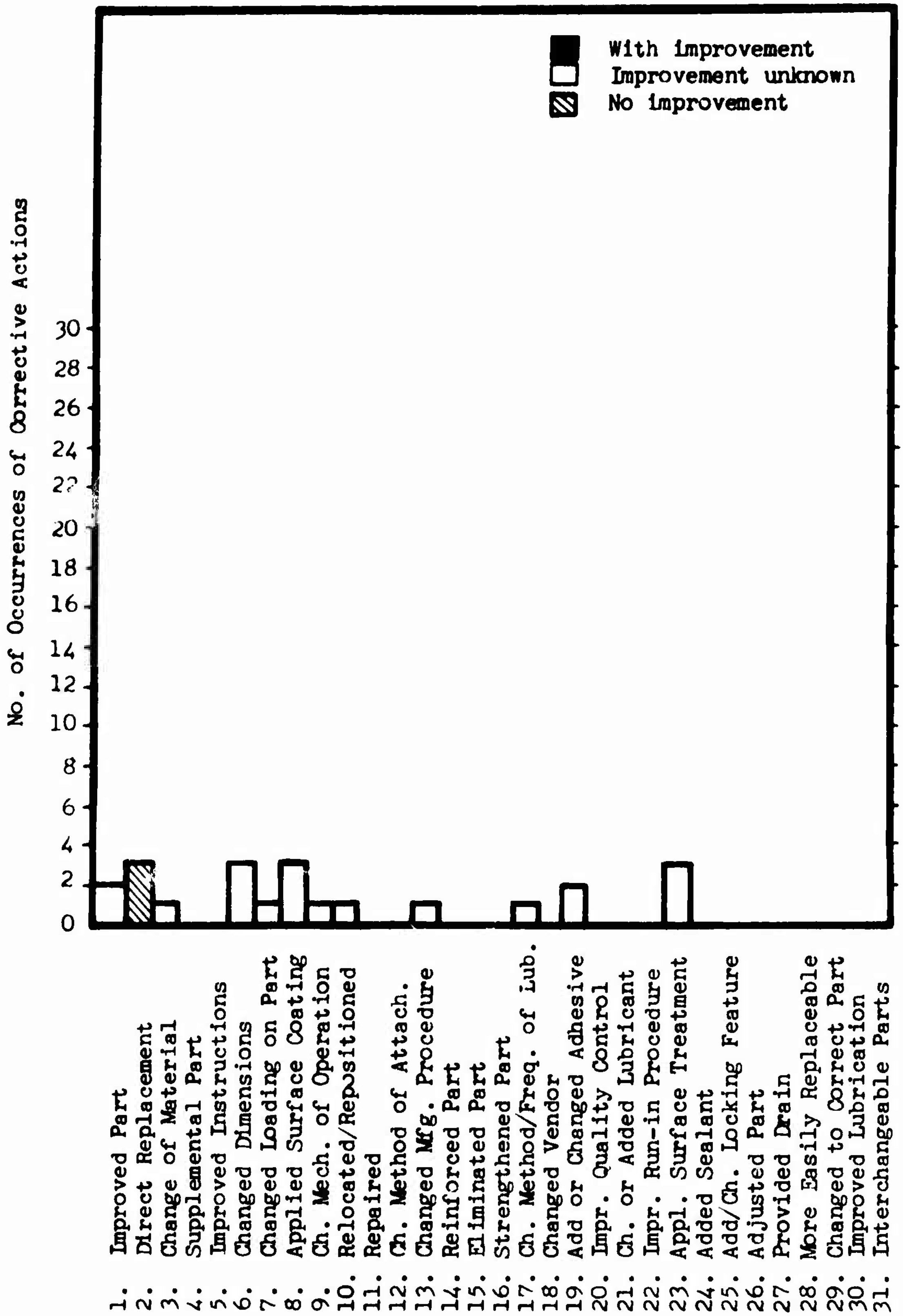


Figure 15. Frequency of Corrective Action Usage for <u>Fretting-Corrosion</u> Failure Mode - Series I.

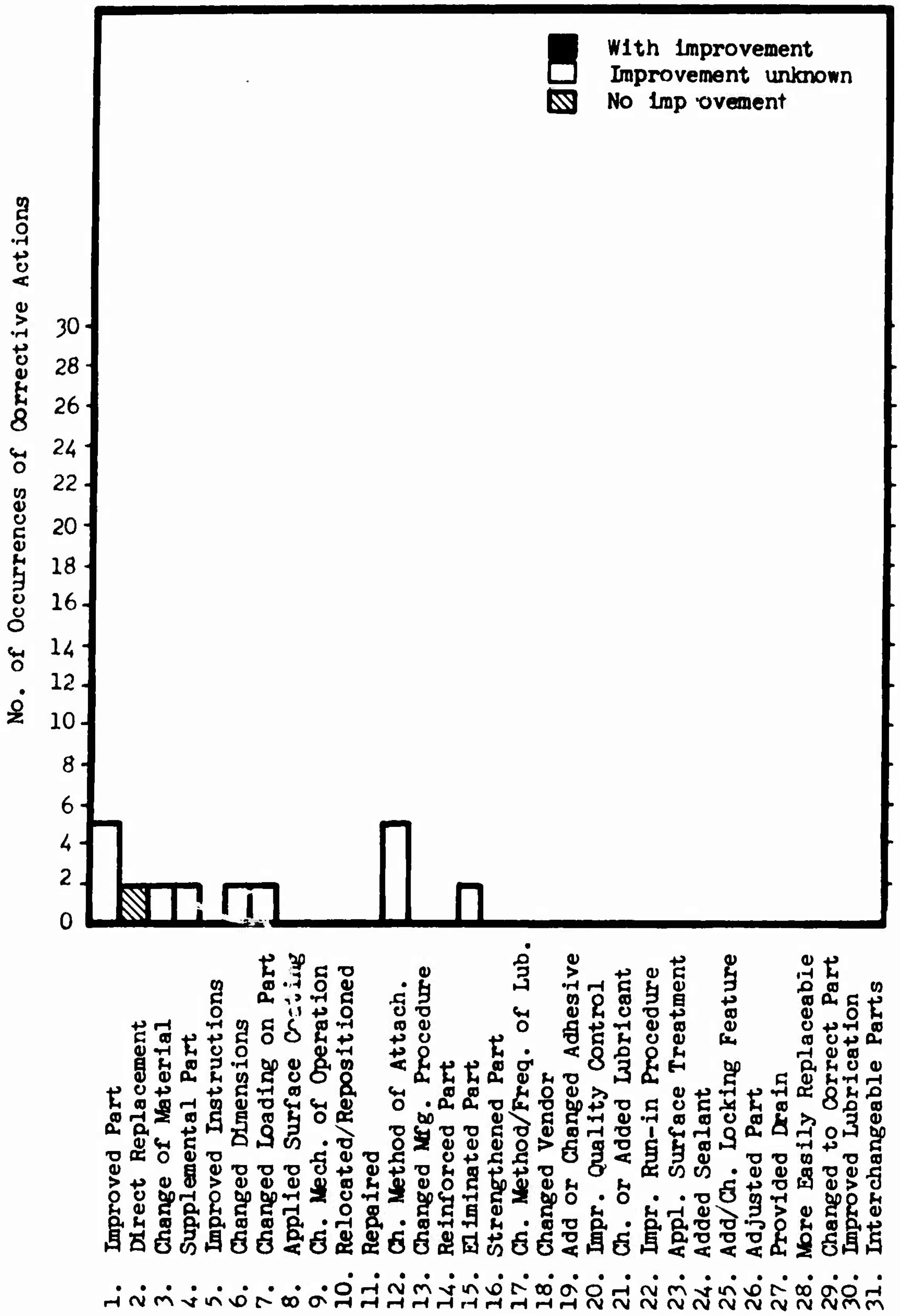


Figure 16. Frequency of Corrective Action Usage for Fretting-Wear Failure Mode - Series I.

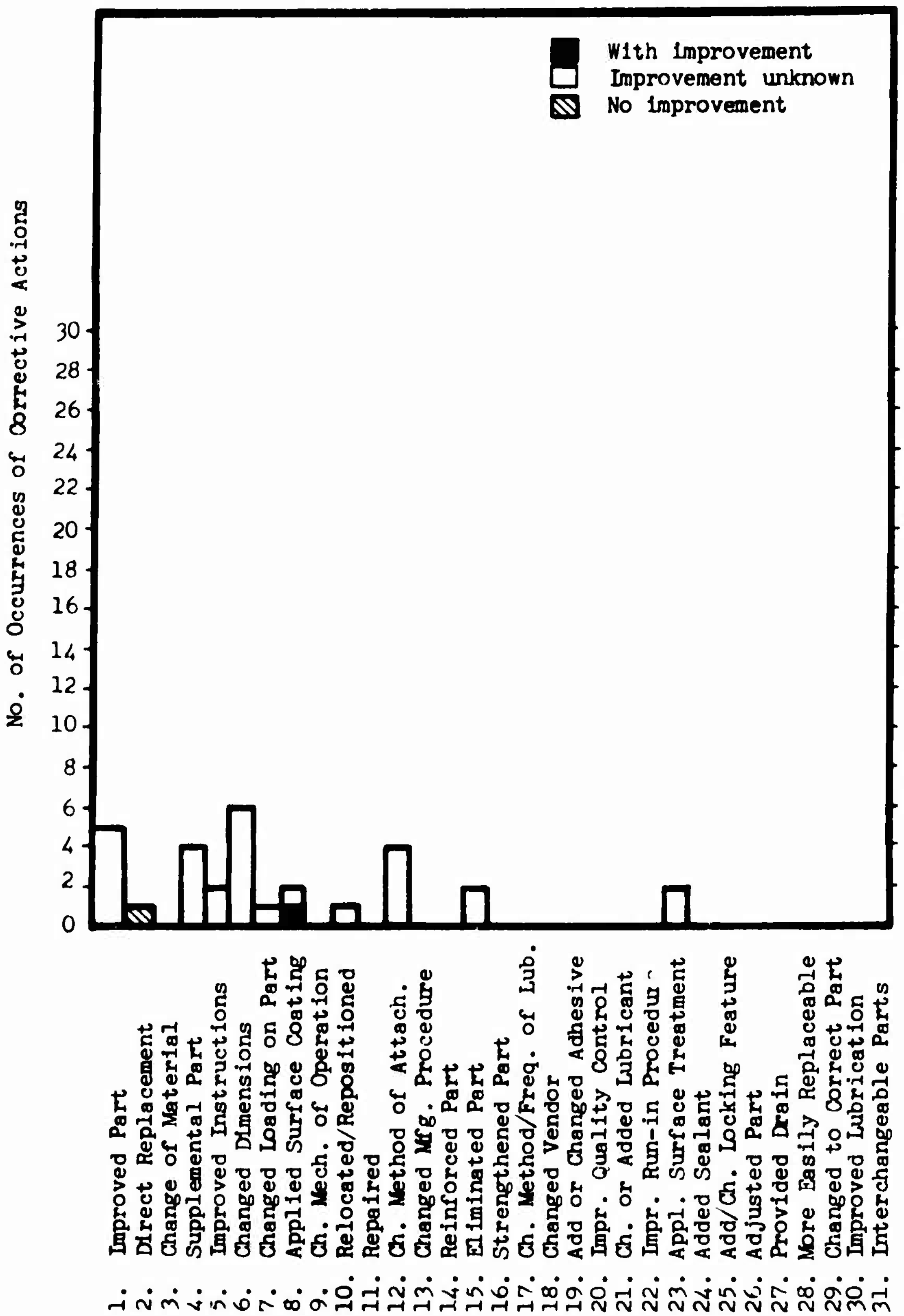


Figure 17. Frequency of Corrective Action Usage for <u>Fretting-Fatigue</u> Failure Mode - Series I.

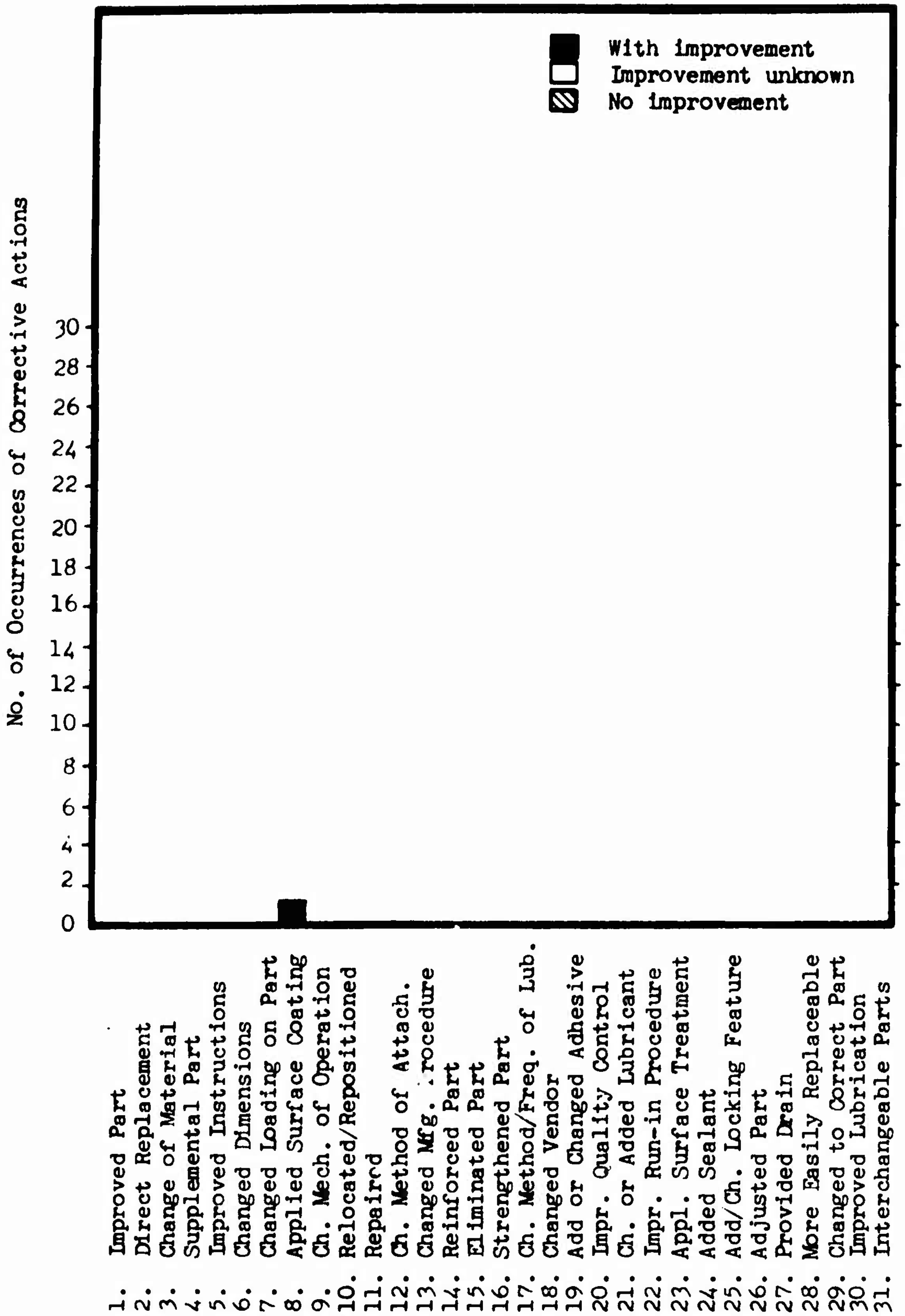


Figure 18. Frequency of Corrective Action Usage for Corrosion-Fatigue Failure Mode - Series I.

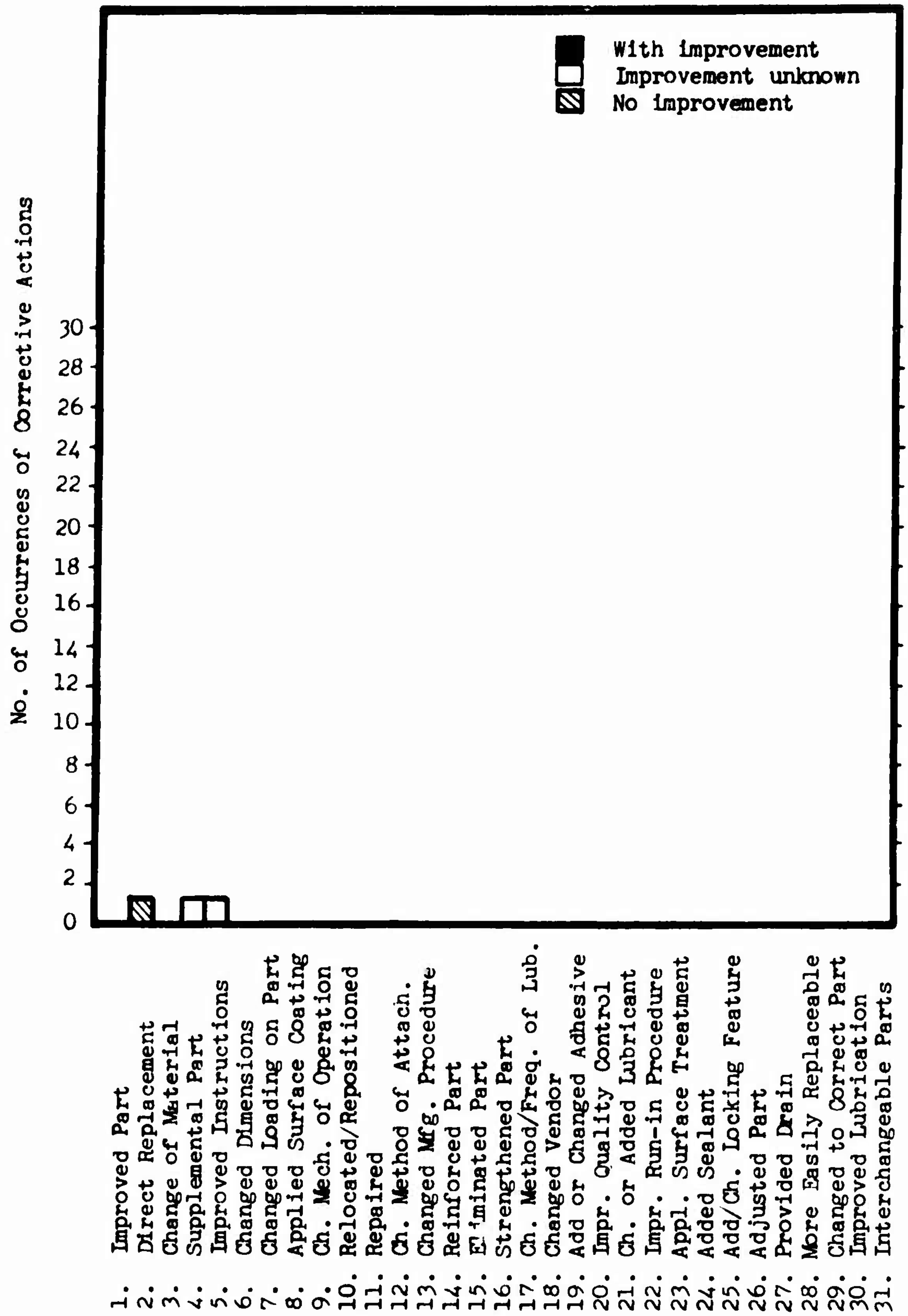


Figure 19. Frequency of Corrective Action Usage for <u>Impact-Fatigue</u> Failure Mode - Series I.

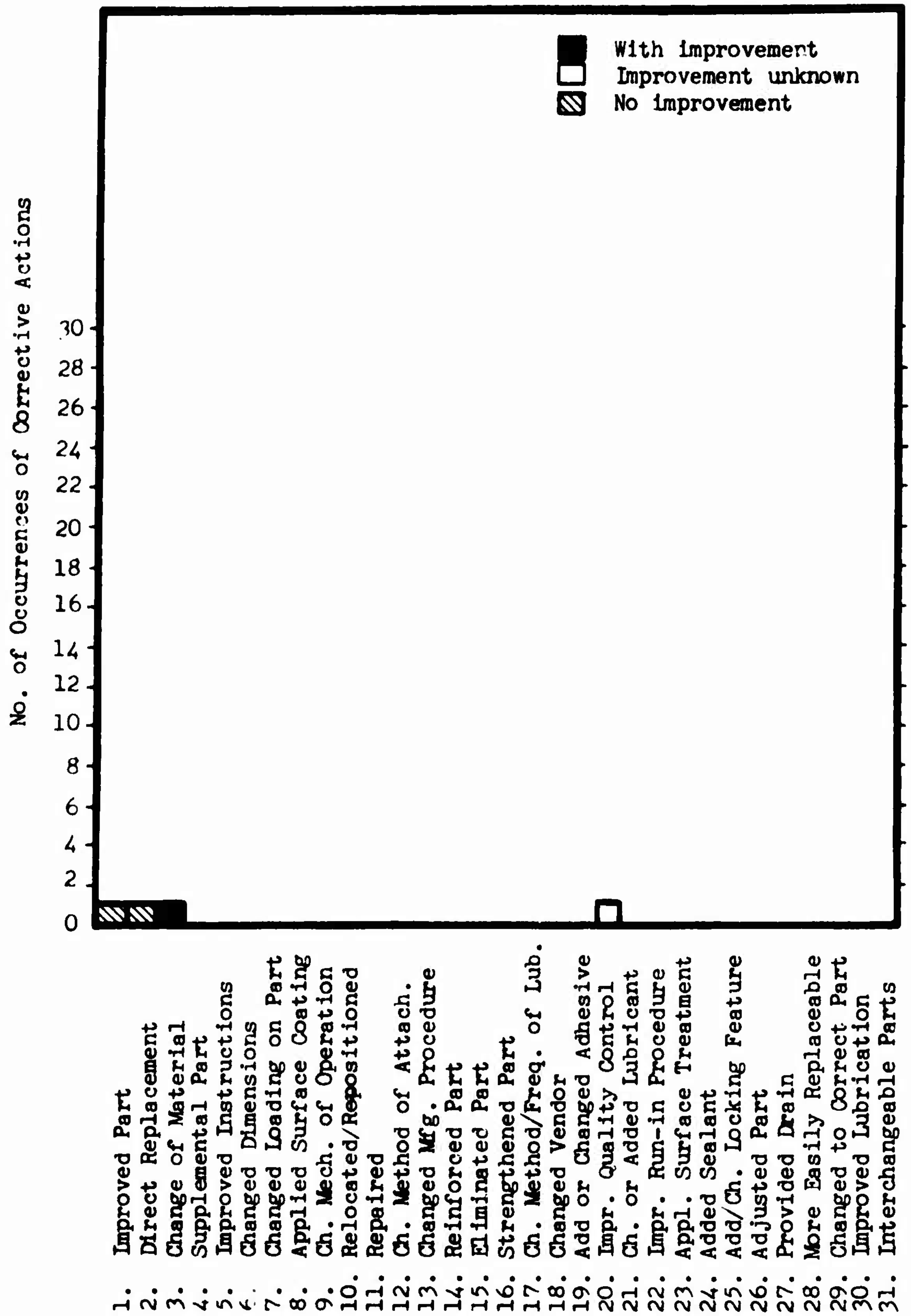


Figure 20. Frequency of Corrective Action Usage for Buckling Failure Mode - Series I.

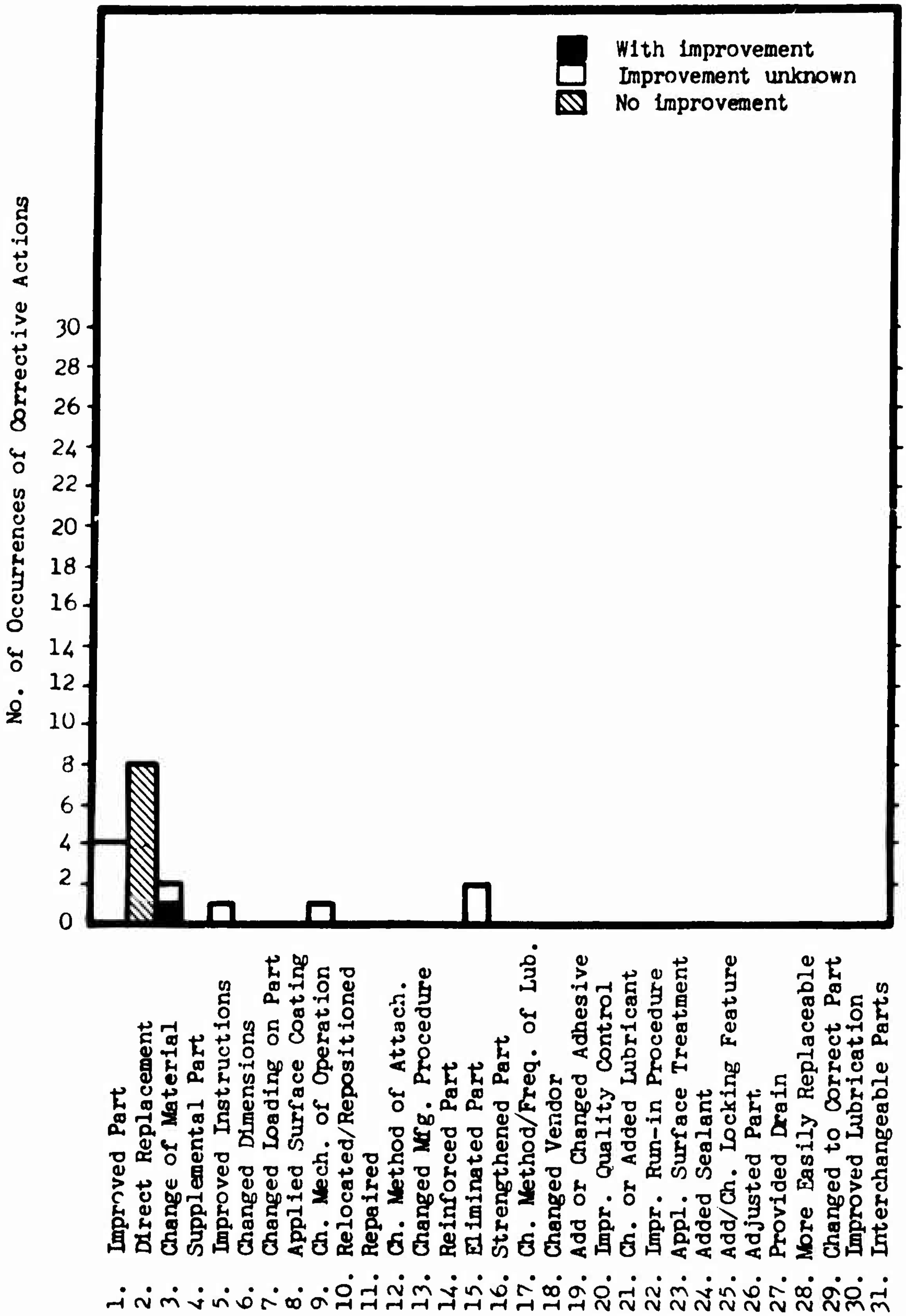


Figure 21. Frequency of Corrective Action Usage for
<u>Change in Material Properties</u> Failure Mode - Ser. I.

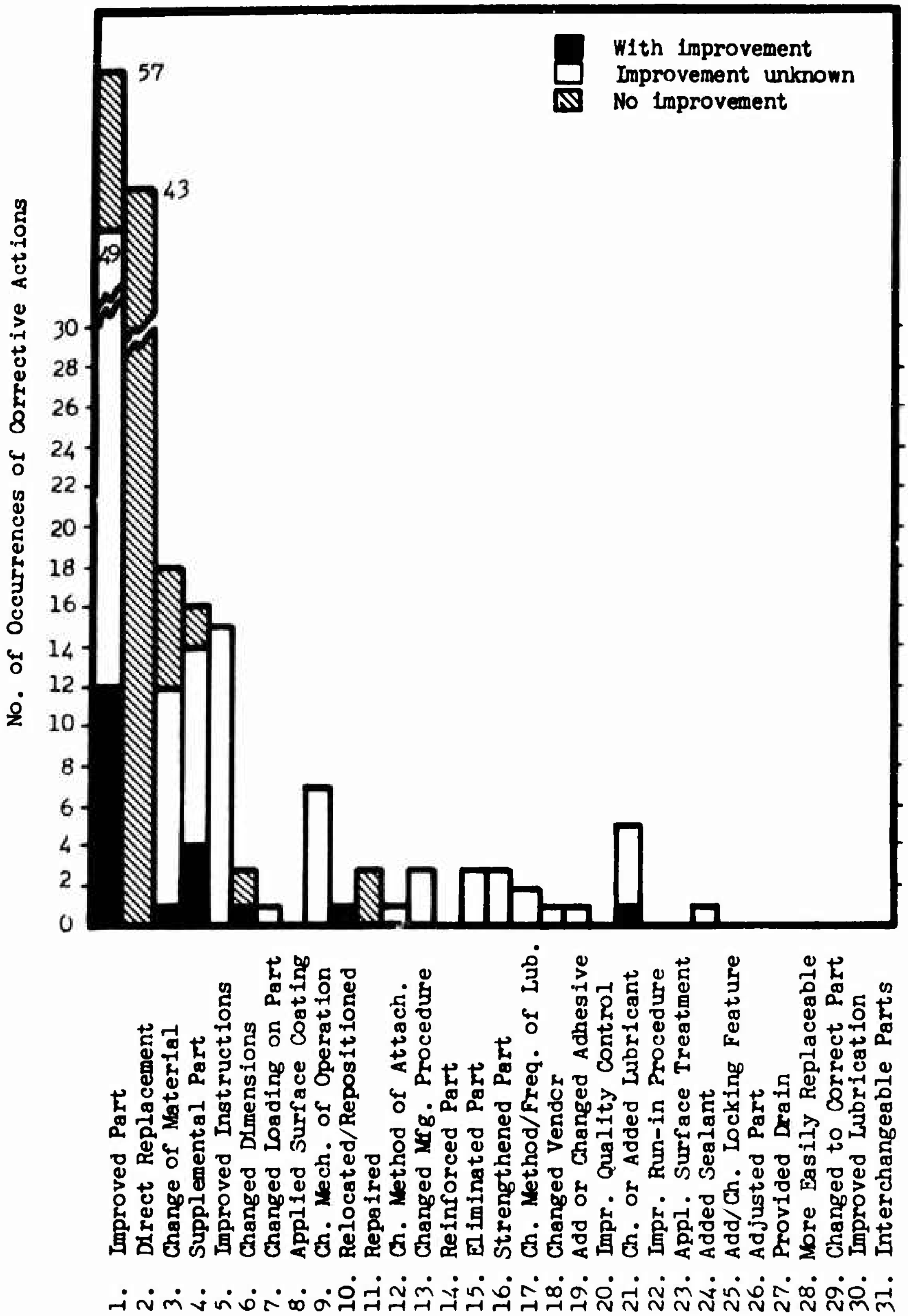


Figure 22. Frequency of Corrective Action Usage for <u>Leakage</u> Failure Mode - Series I.

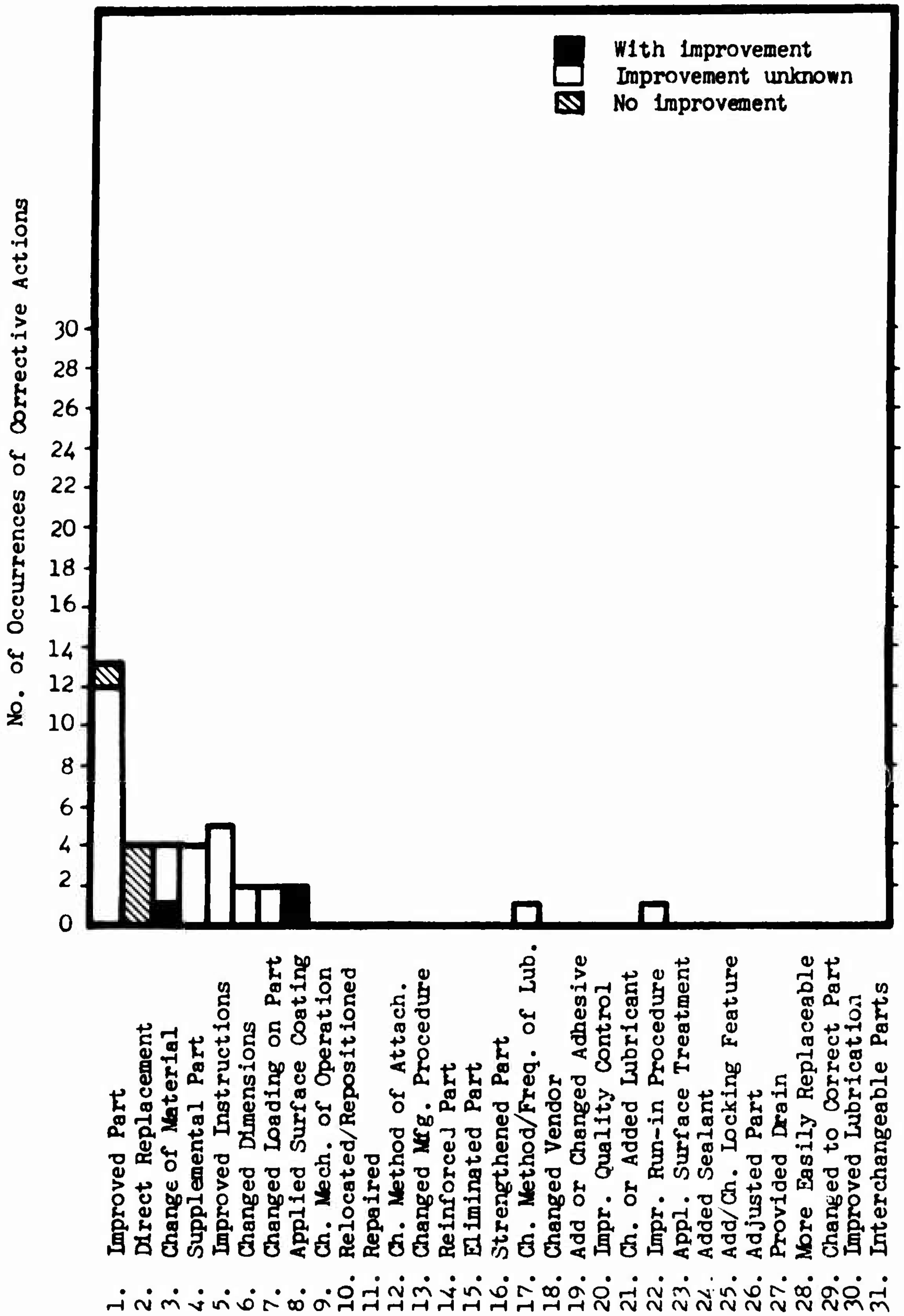


Figure 23. Frequency of Corrective Action Usage for <u>Scoring</u> Failure Mode - Series I.

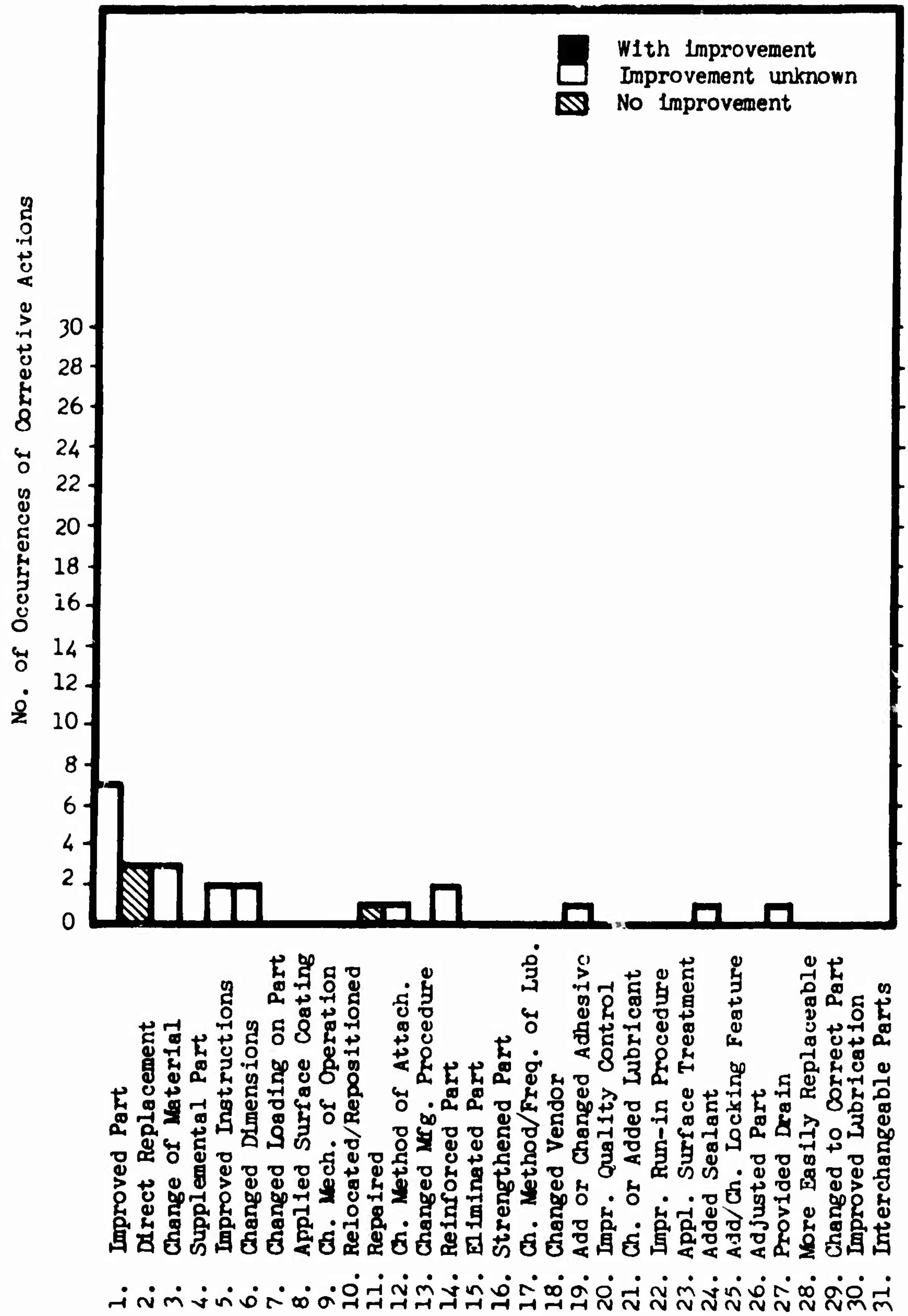


Figure 24. Frequency of Corrective Action Usage for <u>Delamination</u> Failure Mode - Series I.

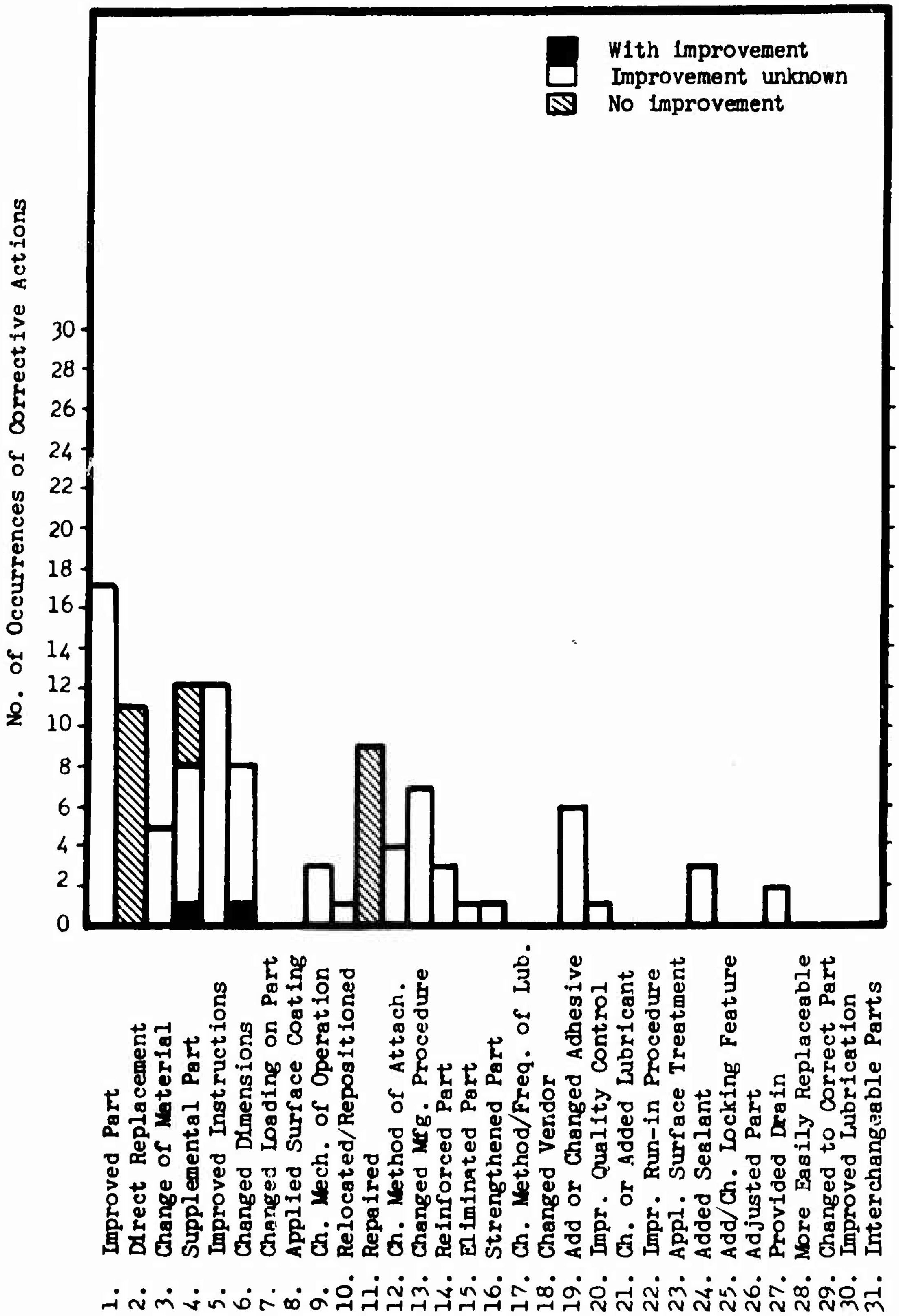


Figure 25. Frequency of Corrective Action Usage for <u>Bonding-Failure</u> Failure Mode - Series I.

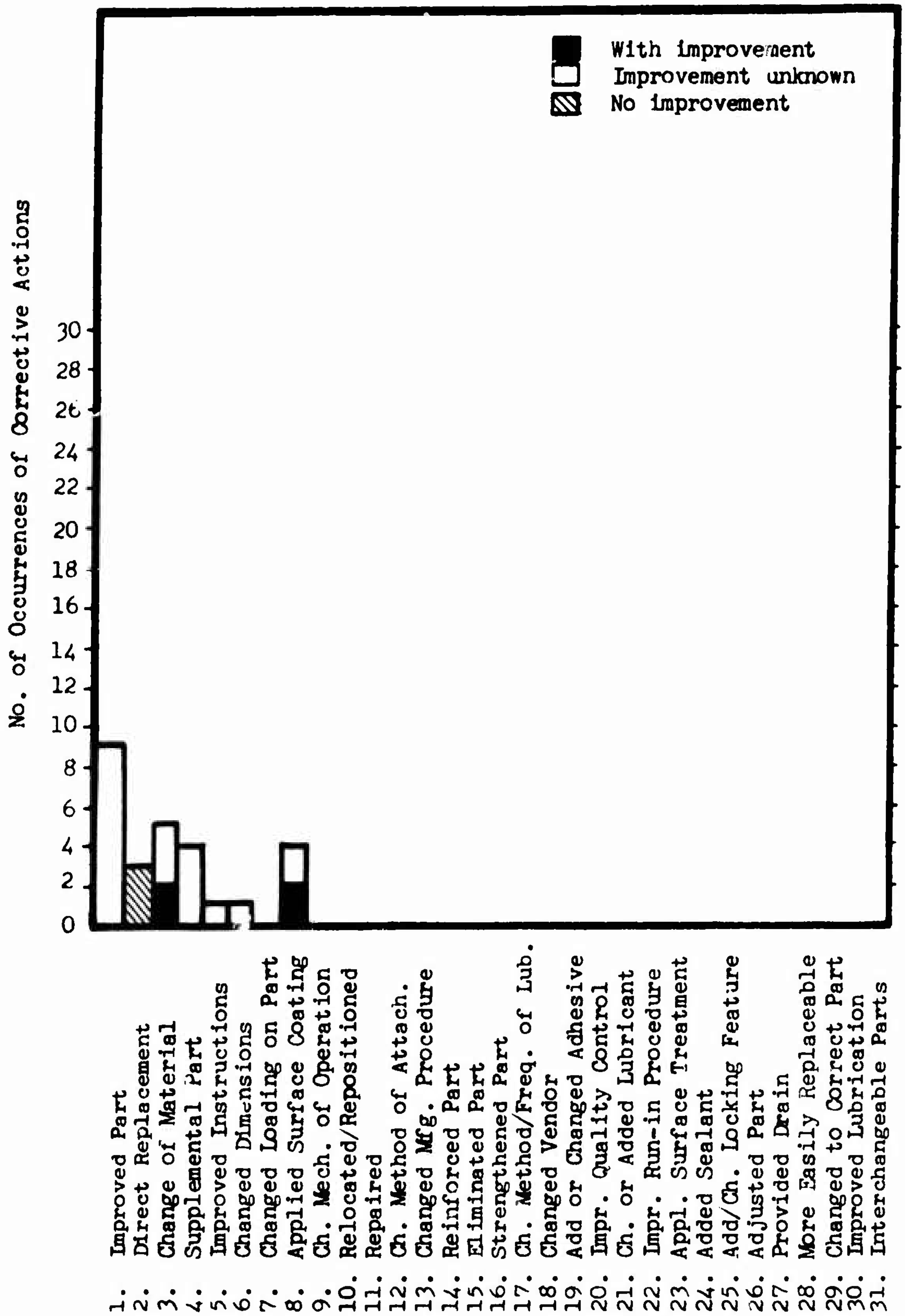


Figure 26. Frequency of Corrective Action Usage for
<u>Erosion</u> Failure Mode - Series I.

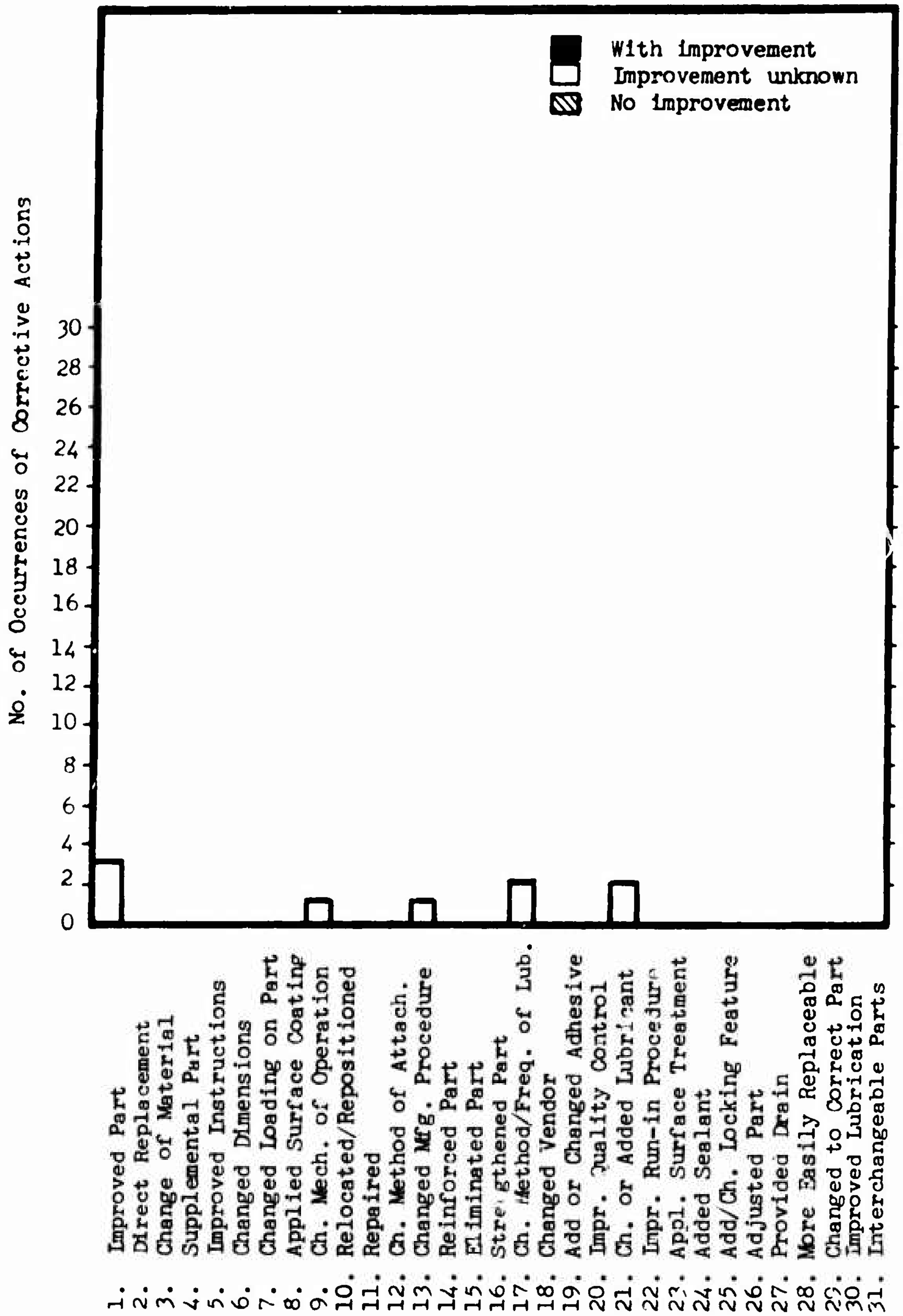


Figure 27. Frequency of Corrective Action Usage for Lubrication-Failure Failure Mode - Series I.

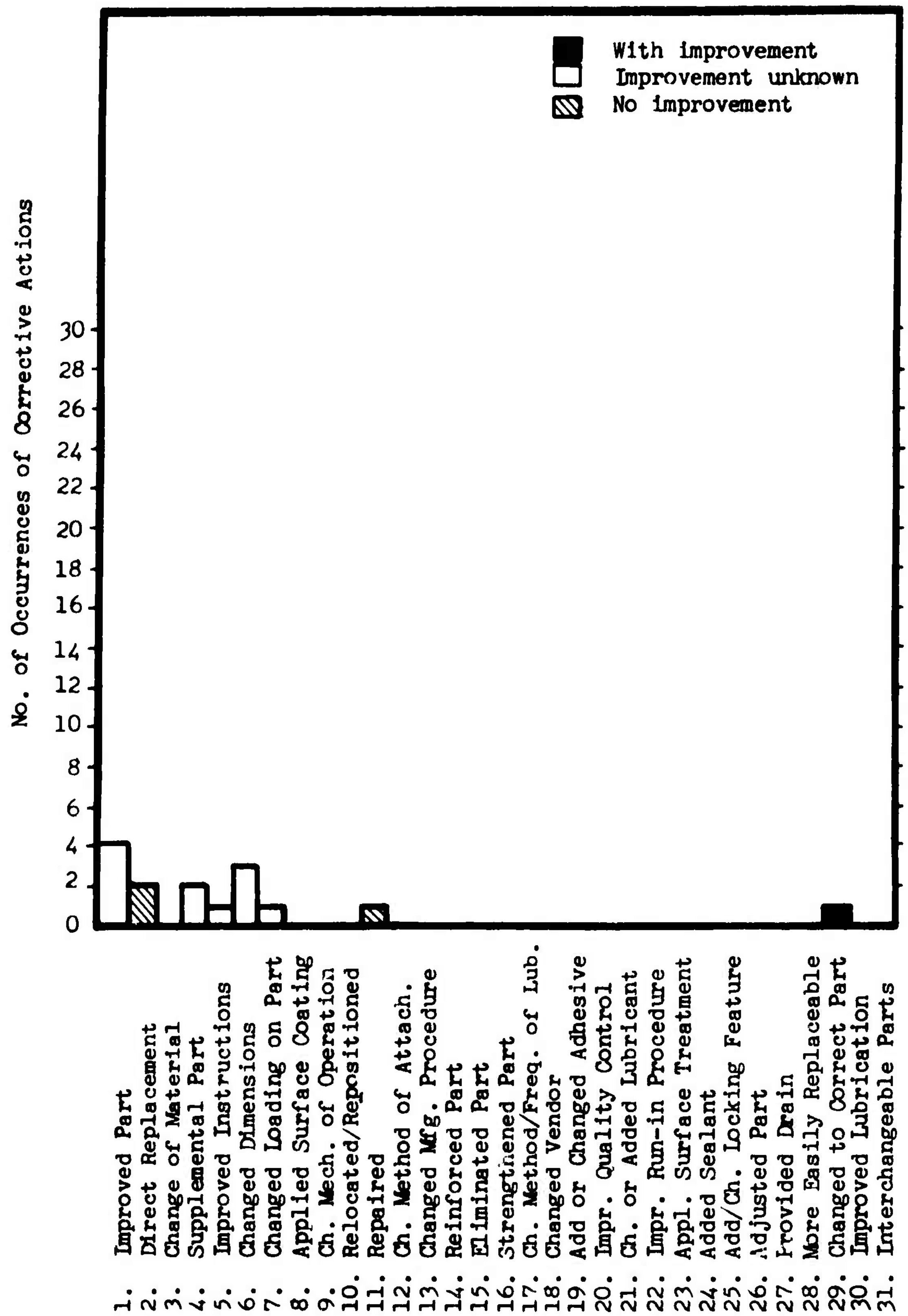


Figure 28. Frequency of Corrective Action Usage for Imbalance Failure Mode - Series I.

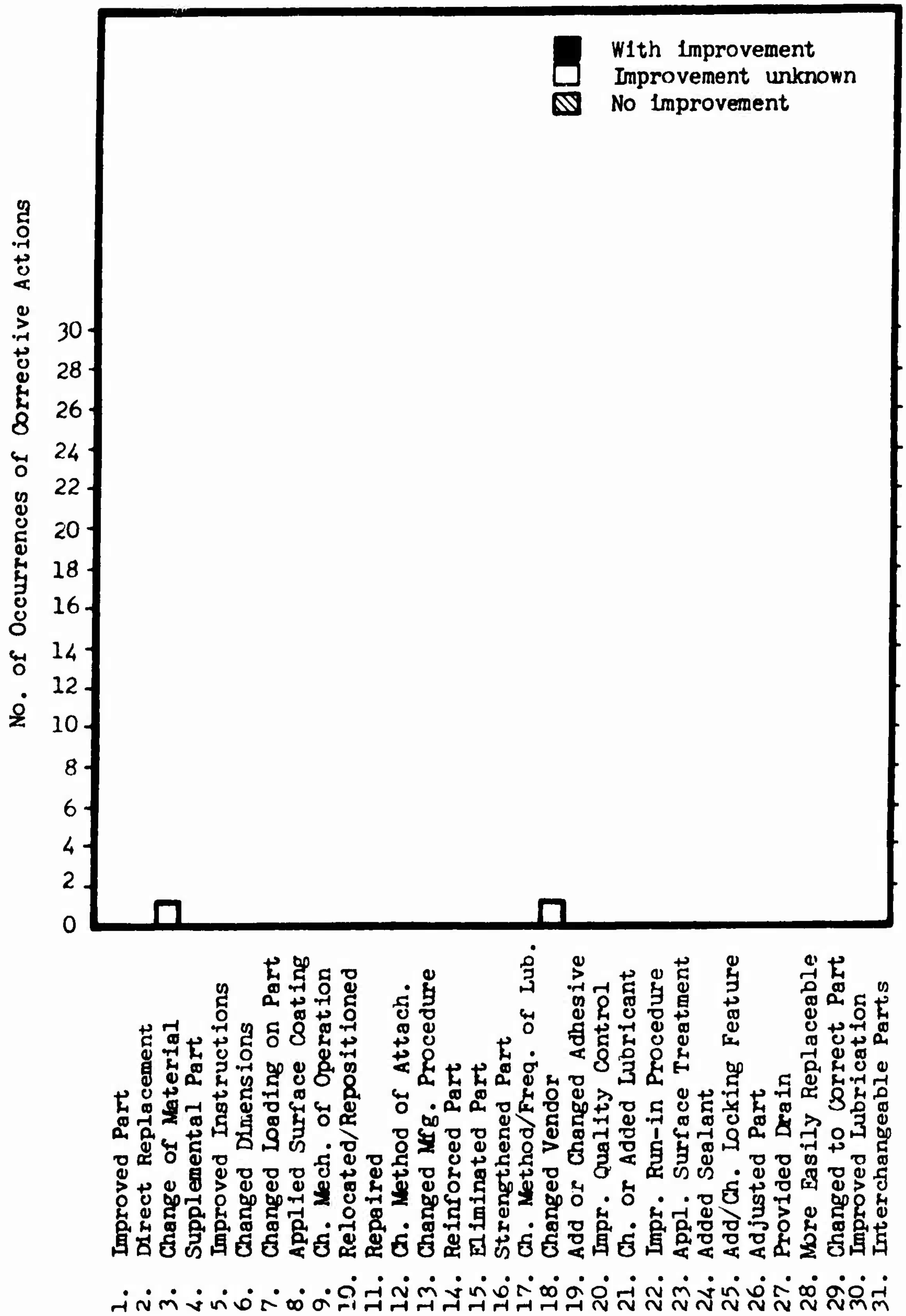


Figure 29. Frequency of Corrective Action Usage for Electrochemical Overheating Failure Mode - Ser. I.

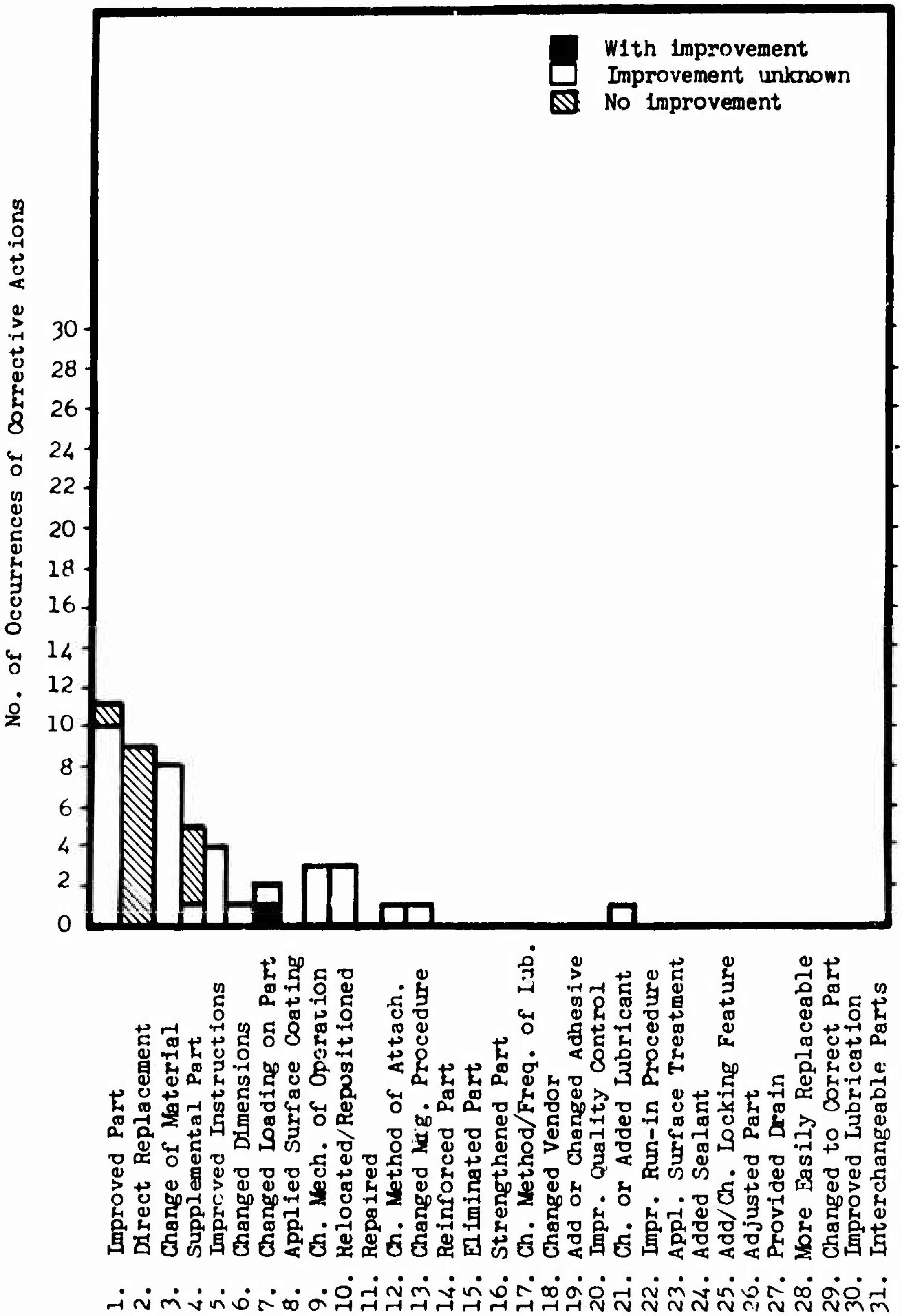


Figure 30. Frequency of Corrective Action Usage for <u>Seizure</u> Failure Mode - Series I.

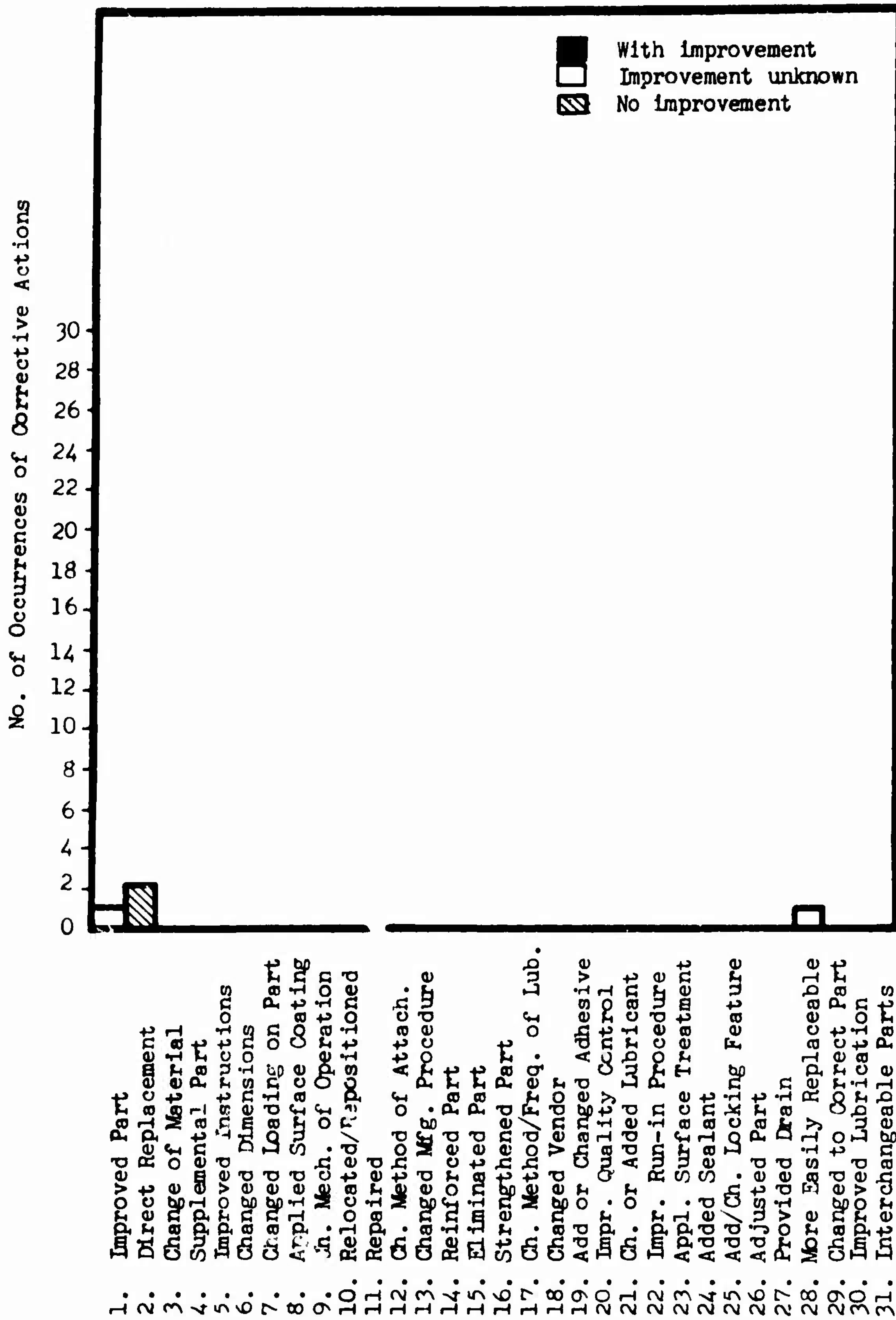


Figure 31. Frequency of Corrective Action Usage for <u>Clogged</u> <u>Filter</u> Failure Mode - Series I.

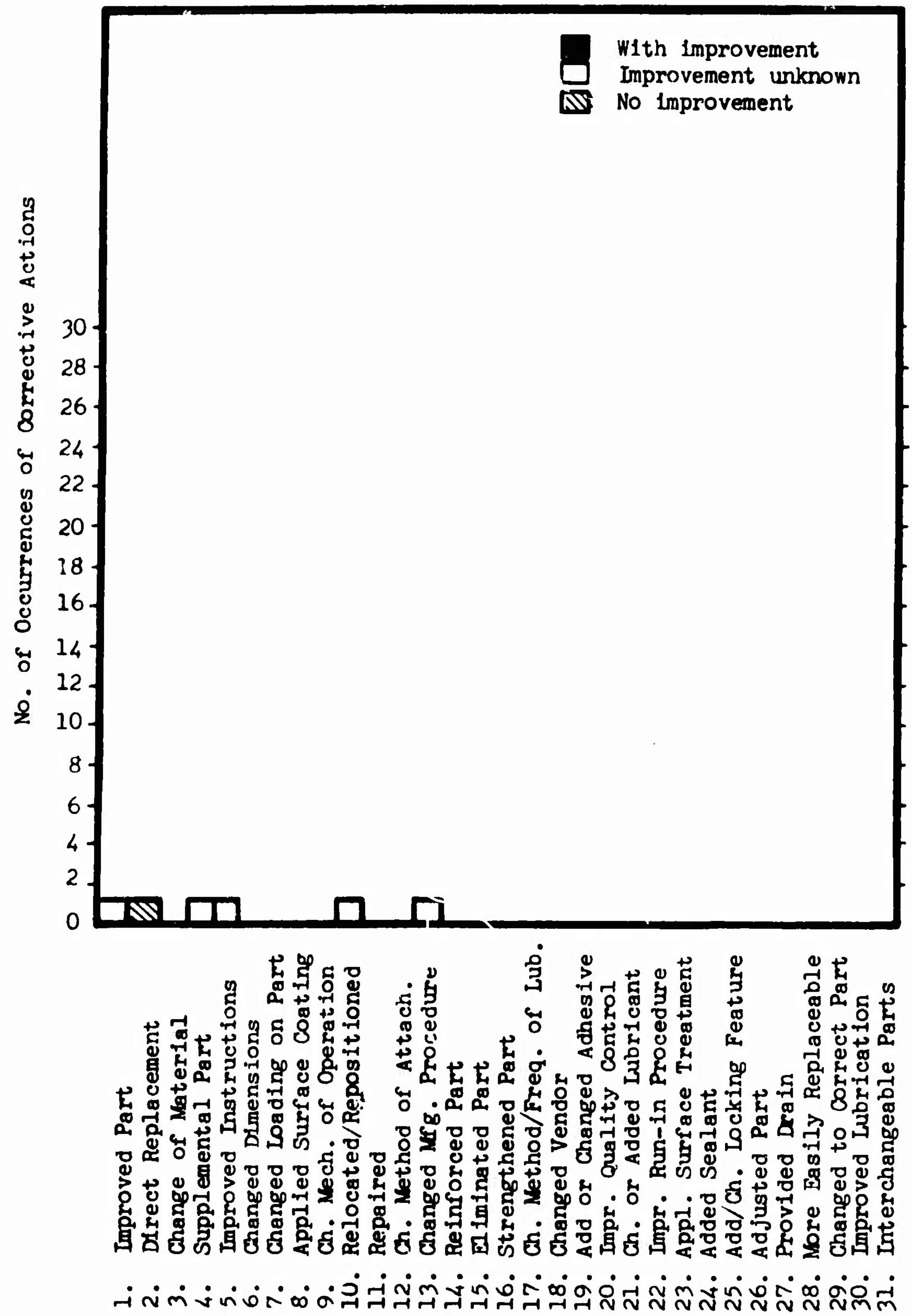


Figure 32. Frequency of Corrective Action Usage for Electrical Failure Mode - Series I.

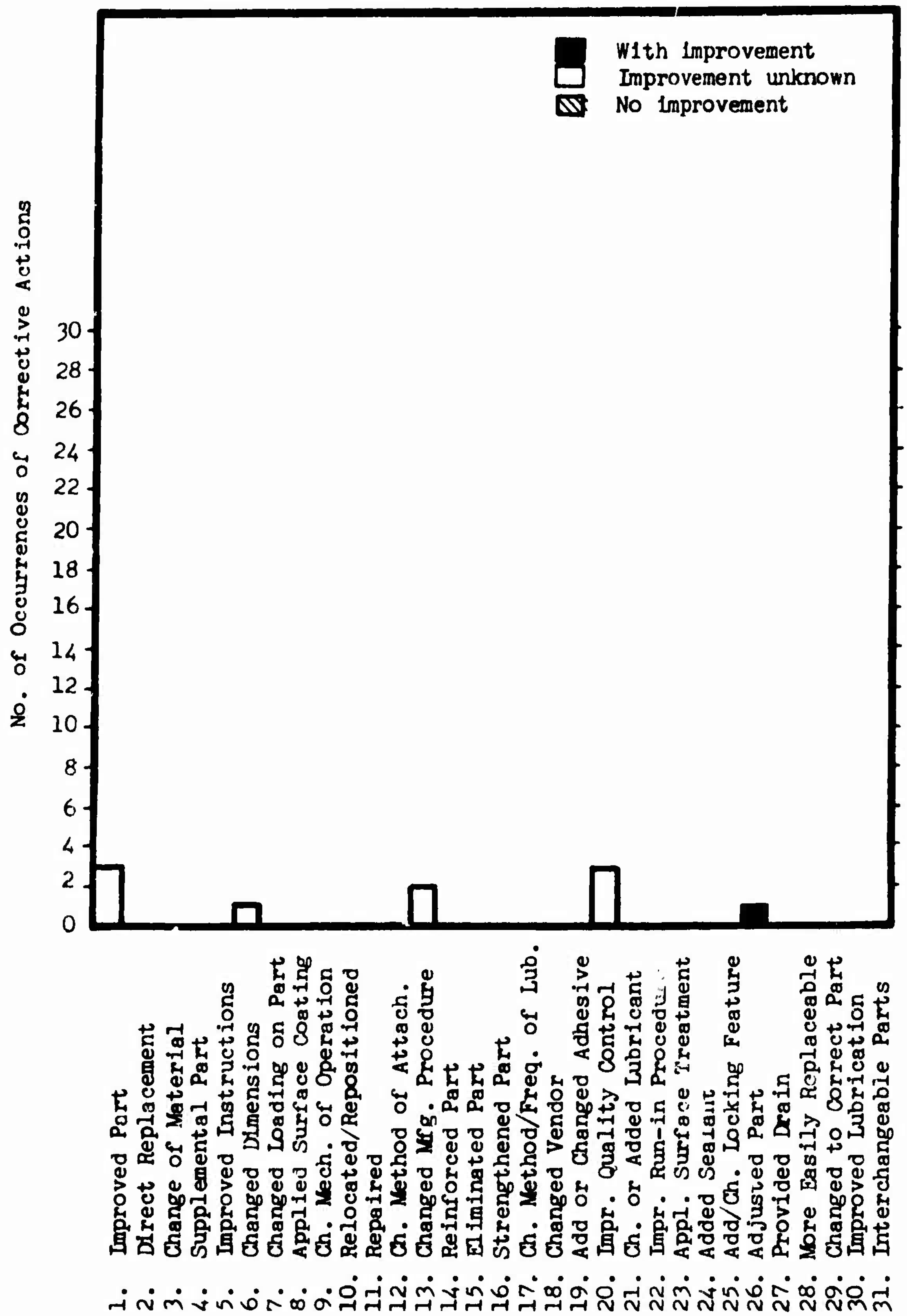


Figure 33. Frequency of Corrective Action Usage for <u>Improper Dimension</u> Failure Mode - Series I.

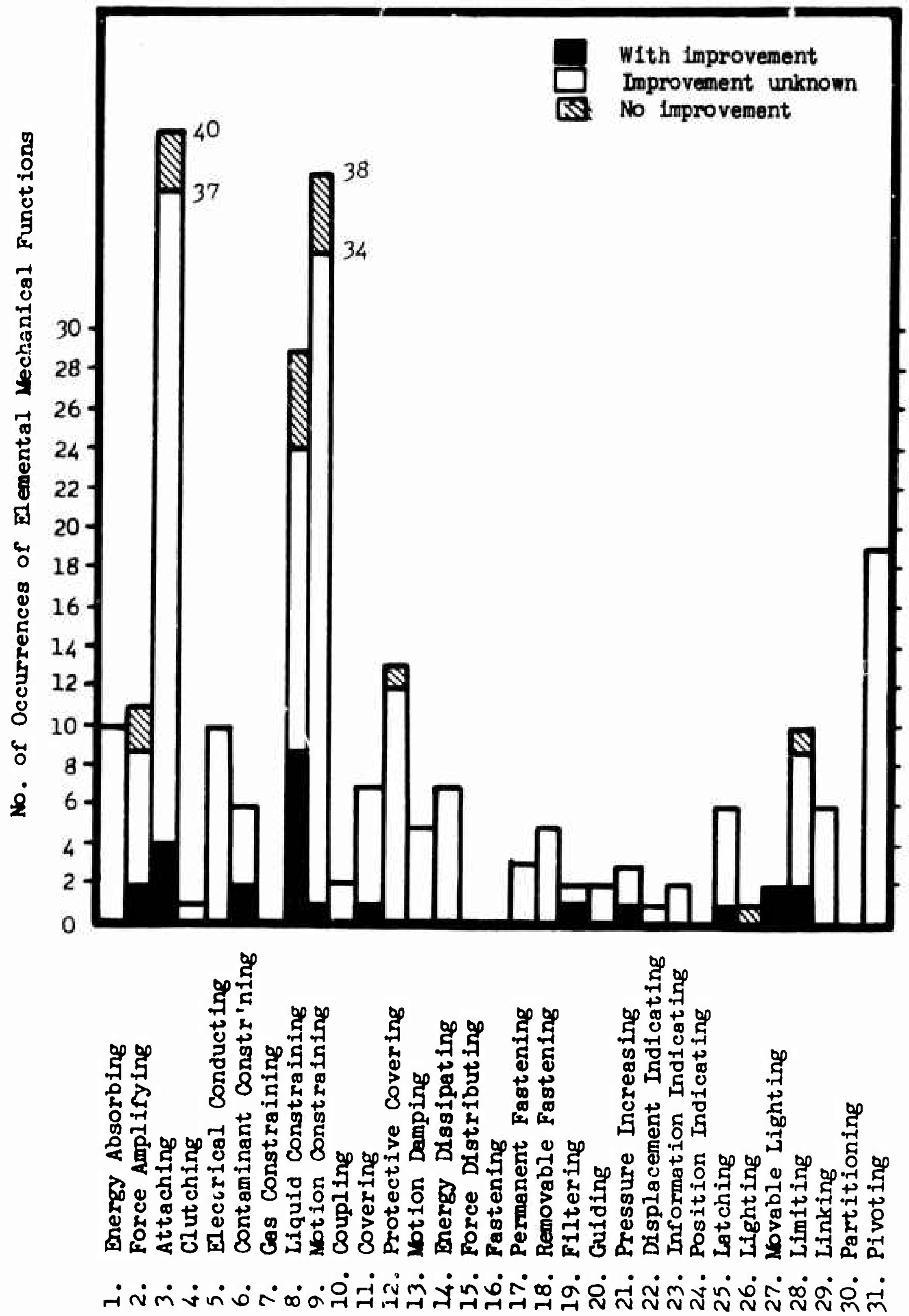


Figure 34. Frequency of Impaired Elemental Functions for the Improved Part Corrective Action - Series II.

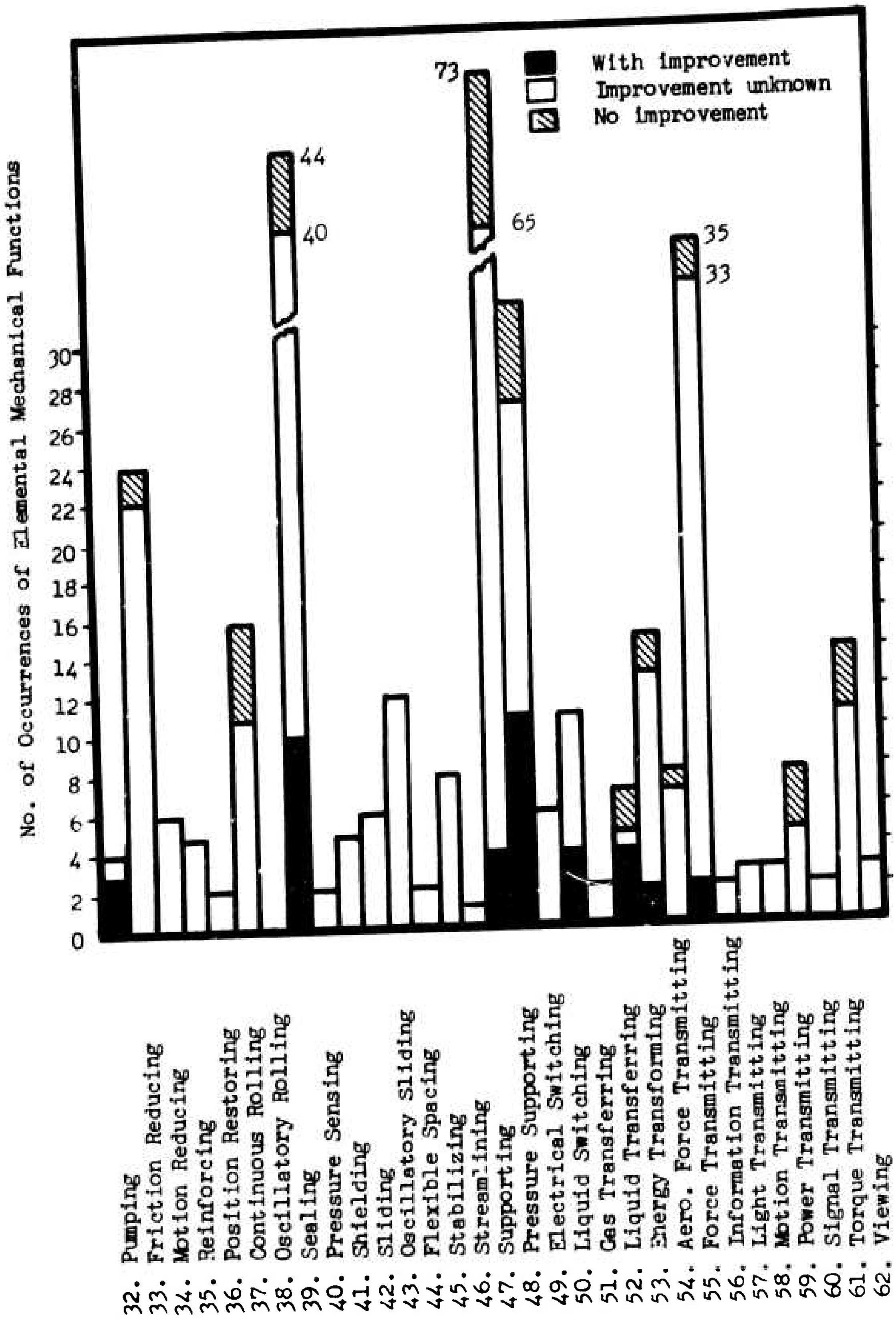


Figure 34 - Continued.

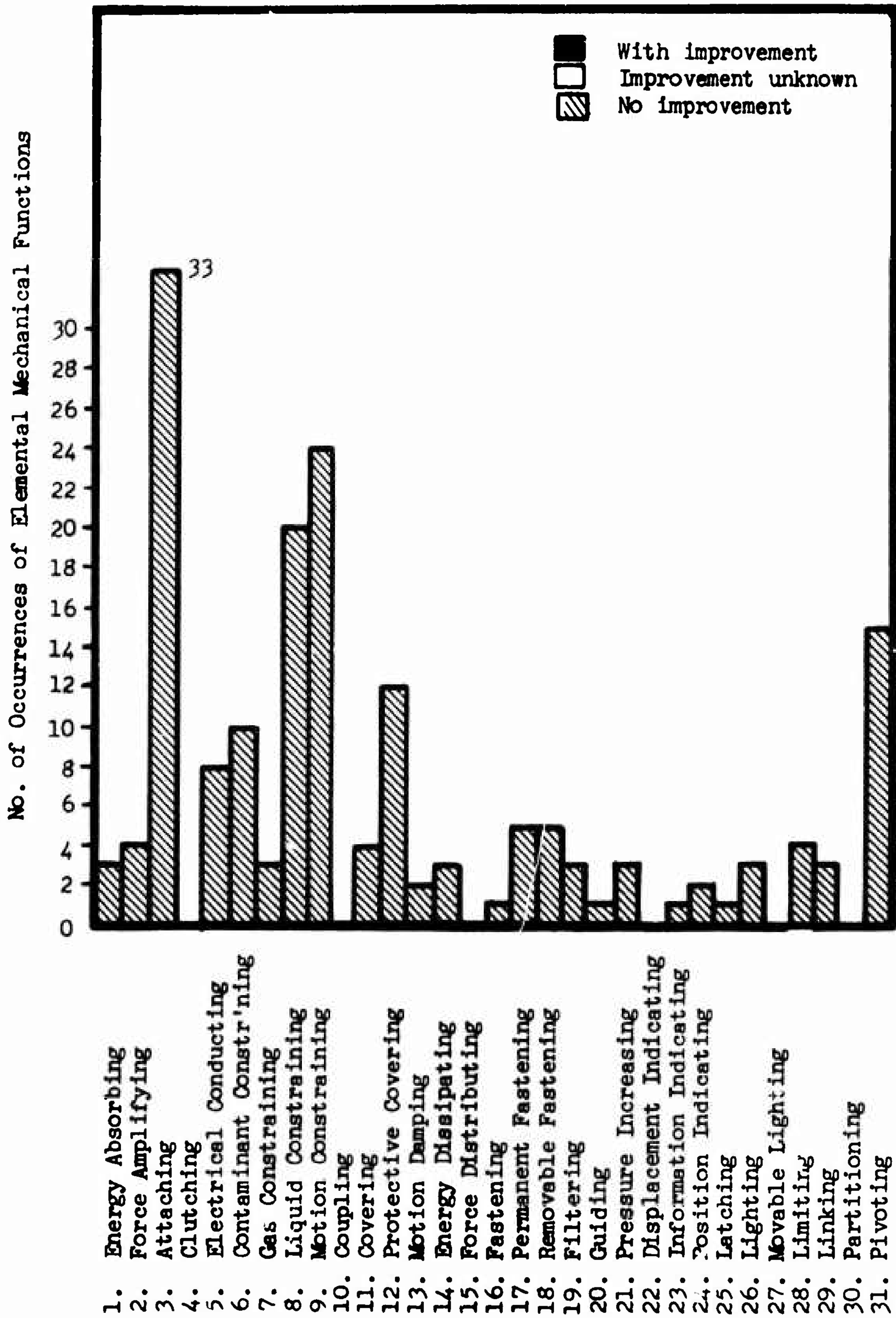


Figure 35. Frequency of Impaired Elemental Functions for the Direct Replacement Corrective Action - Series II.

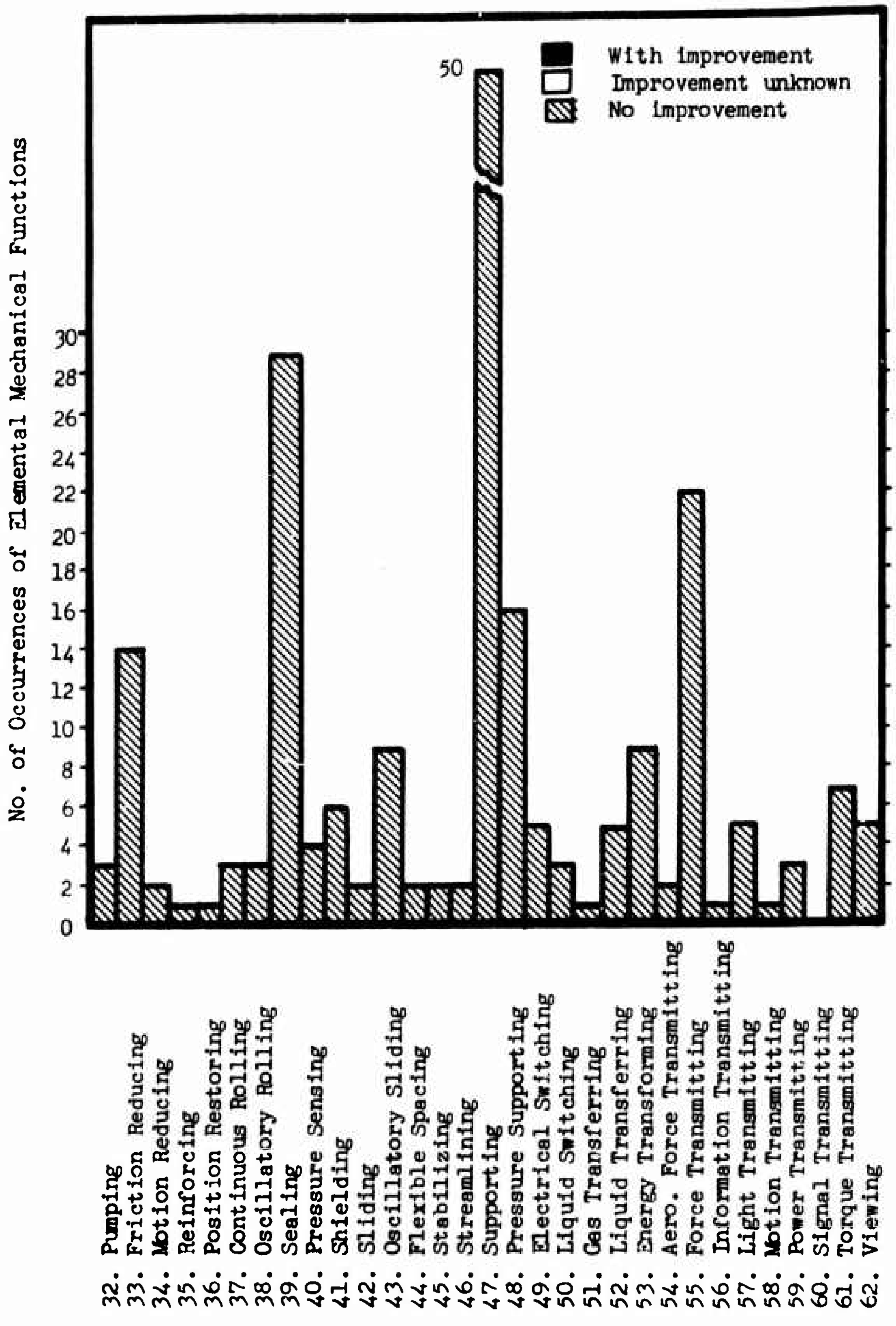


Figure 35 - Continued.

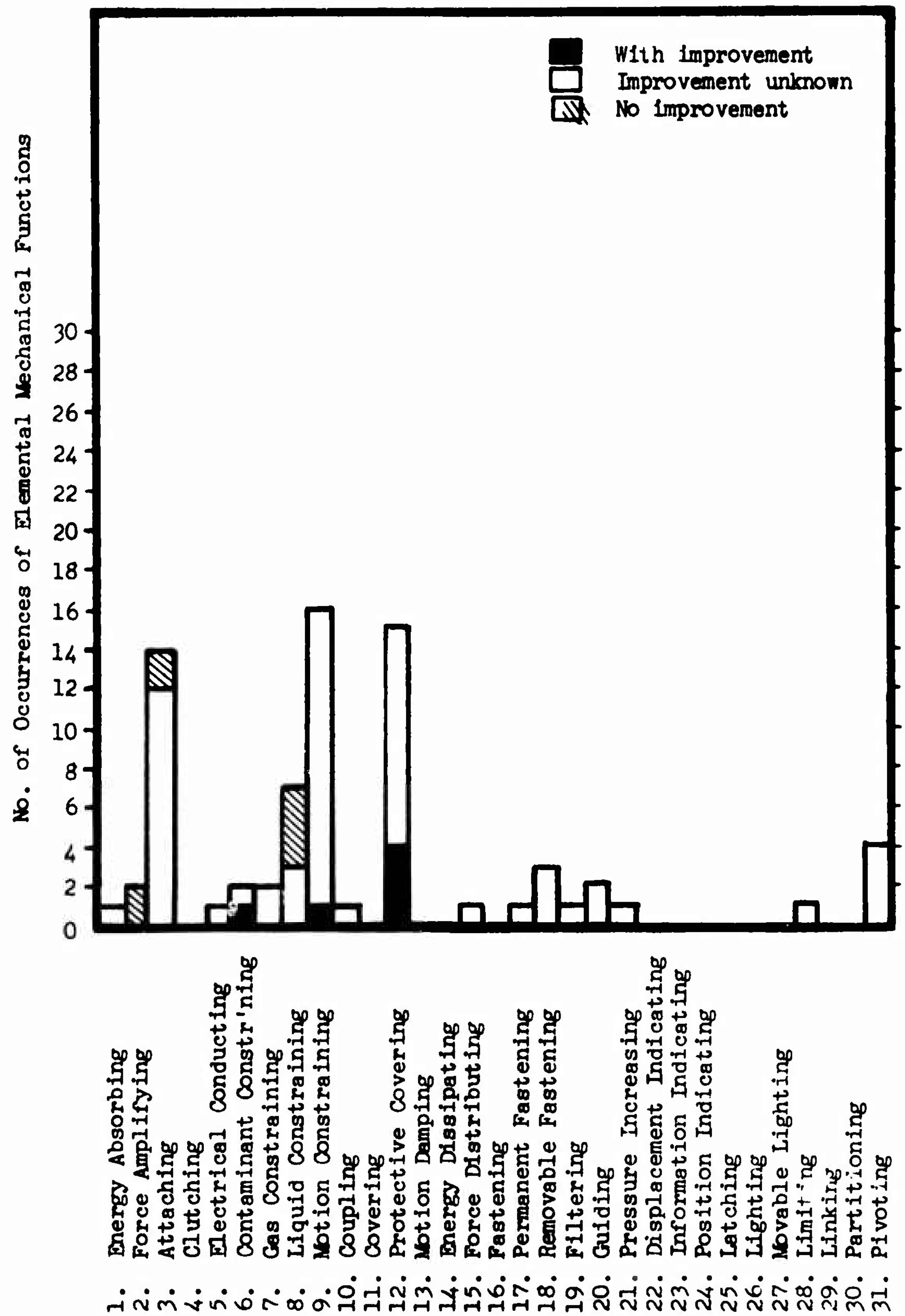


Figure 36. Frequency of Impaired Elemental Functions for the Change of Material Corrective Action - Series II.

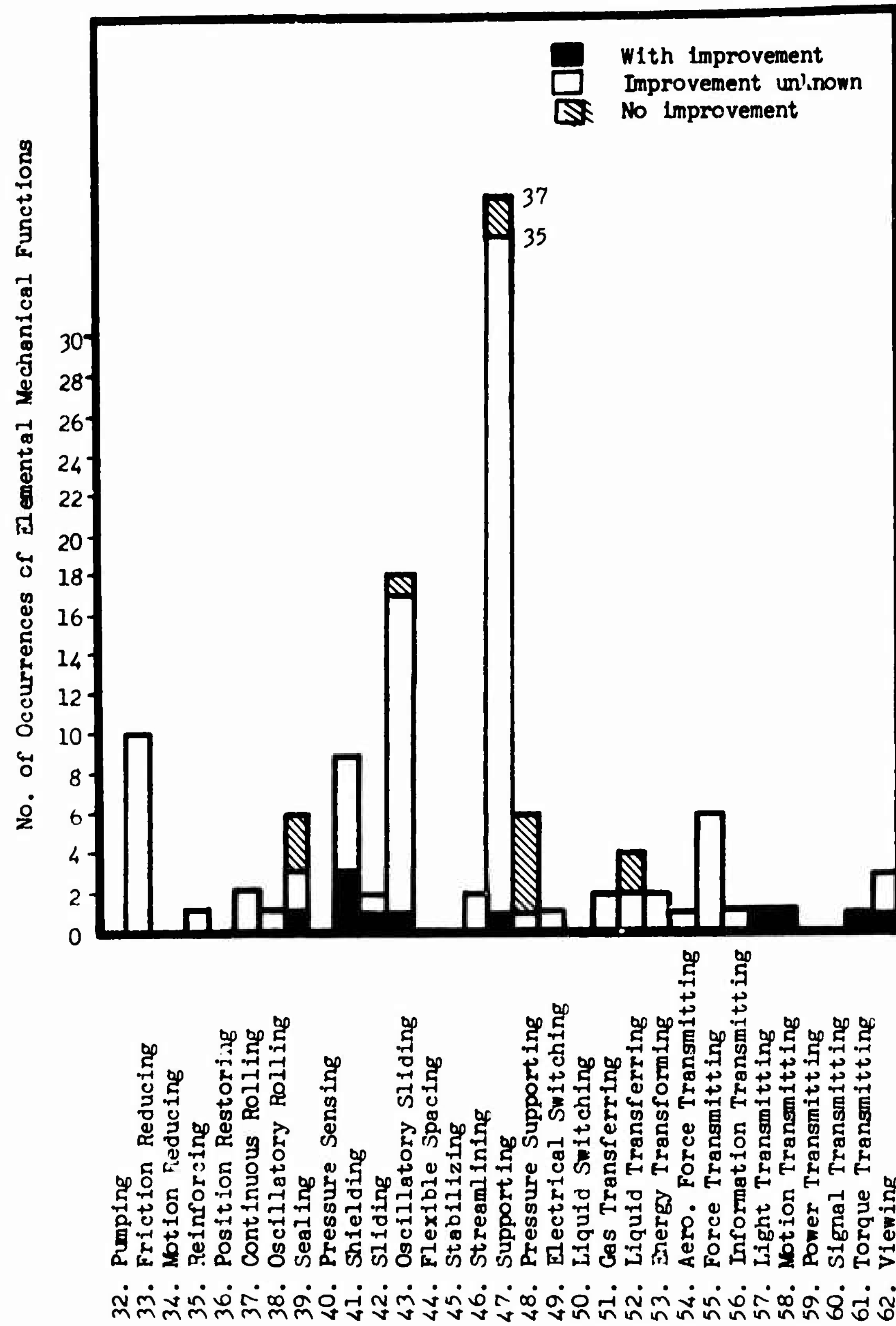


Figure 36 - Continued.

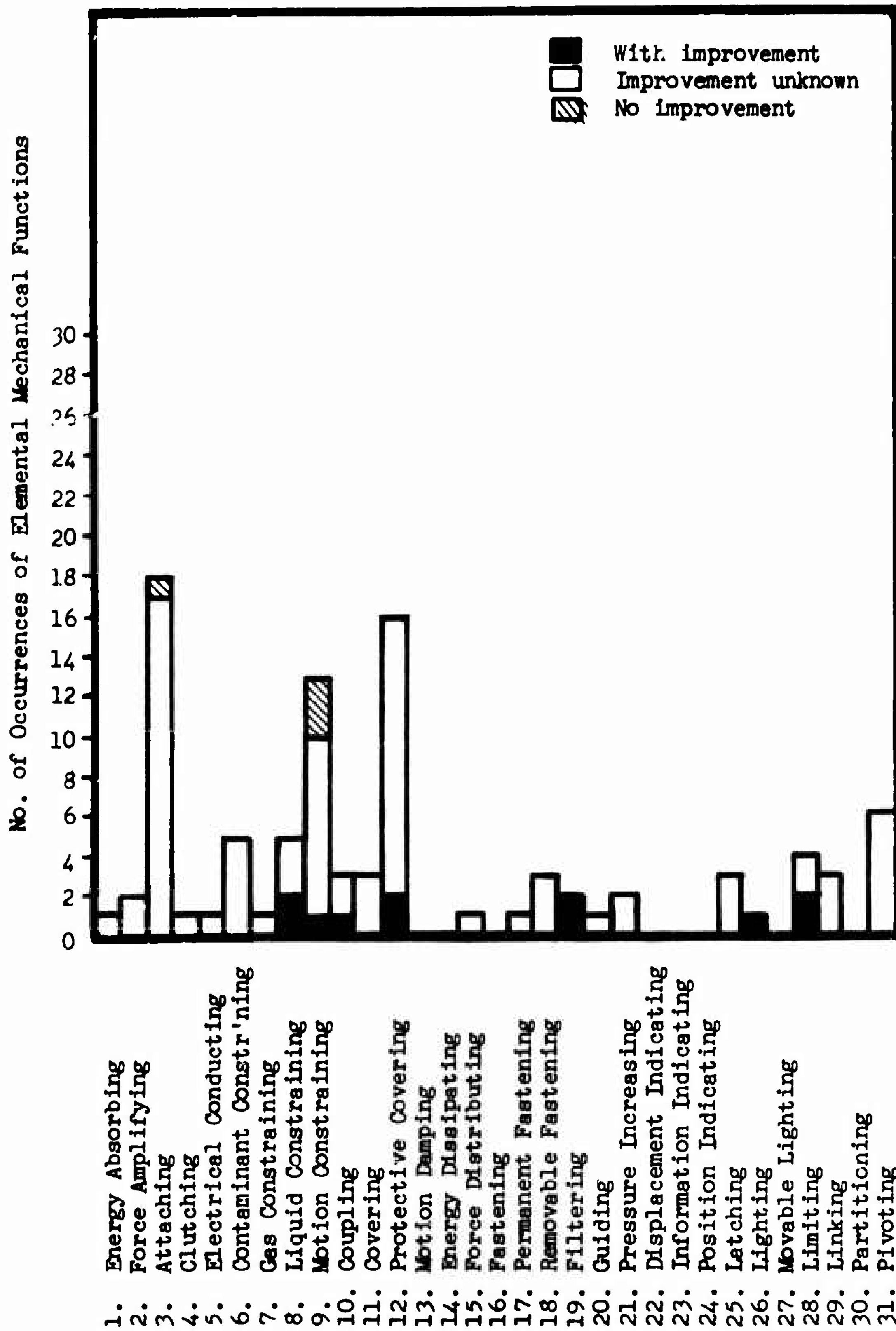


Figure 37. Frequency of Impaired Elemental Functions for the Supplemental Part Corrective Action - Series II.

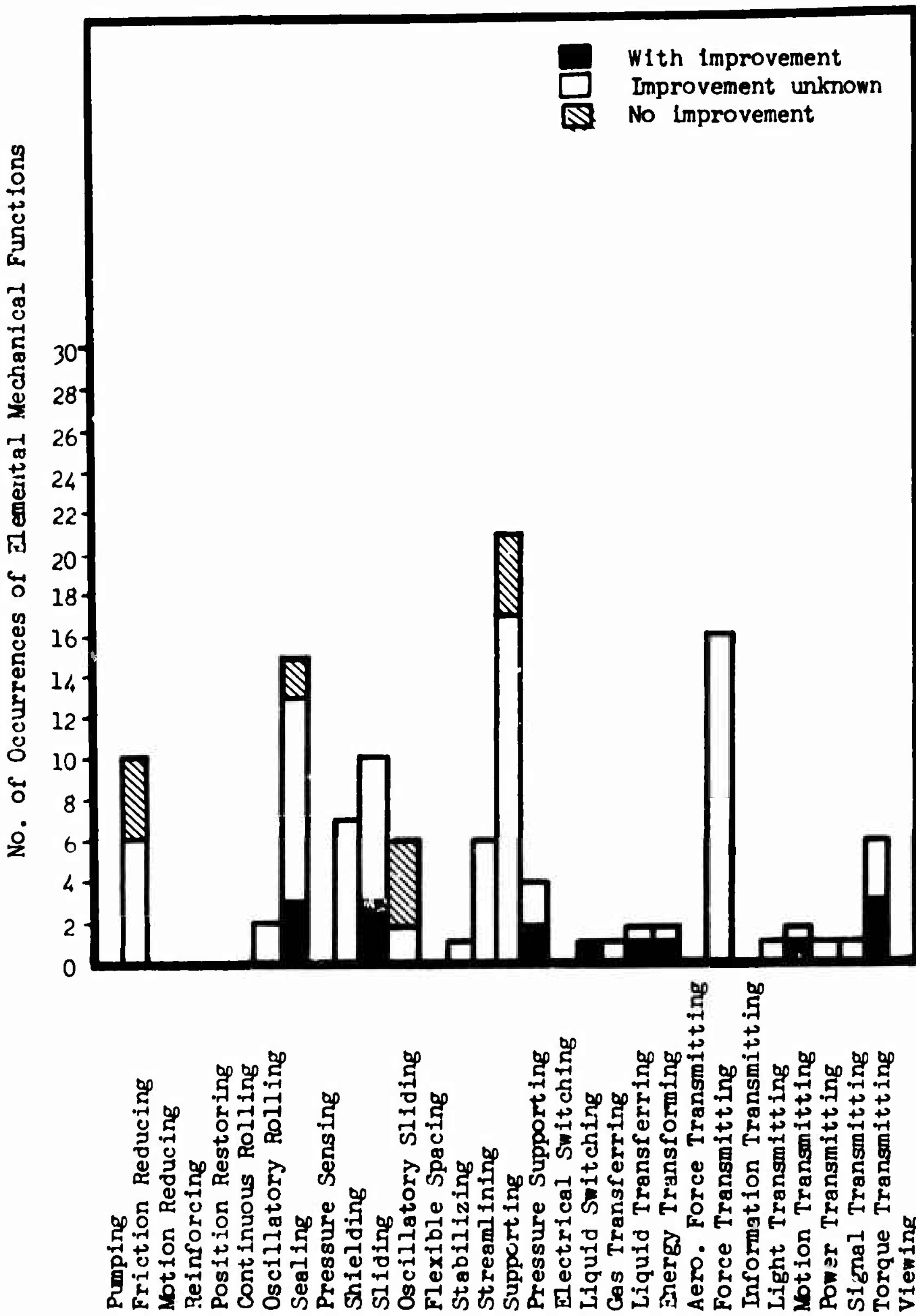


Figure 37 - Continued.

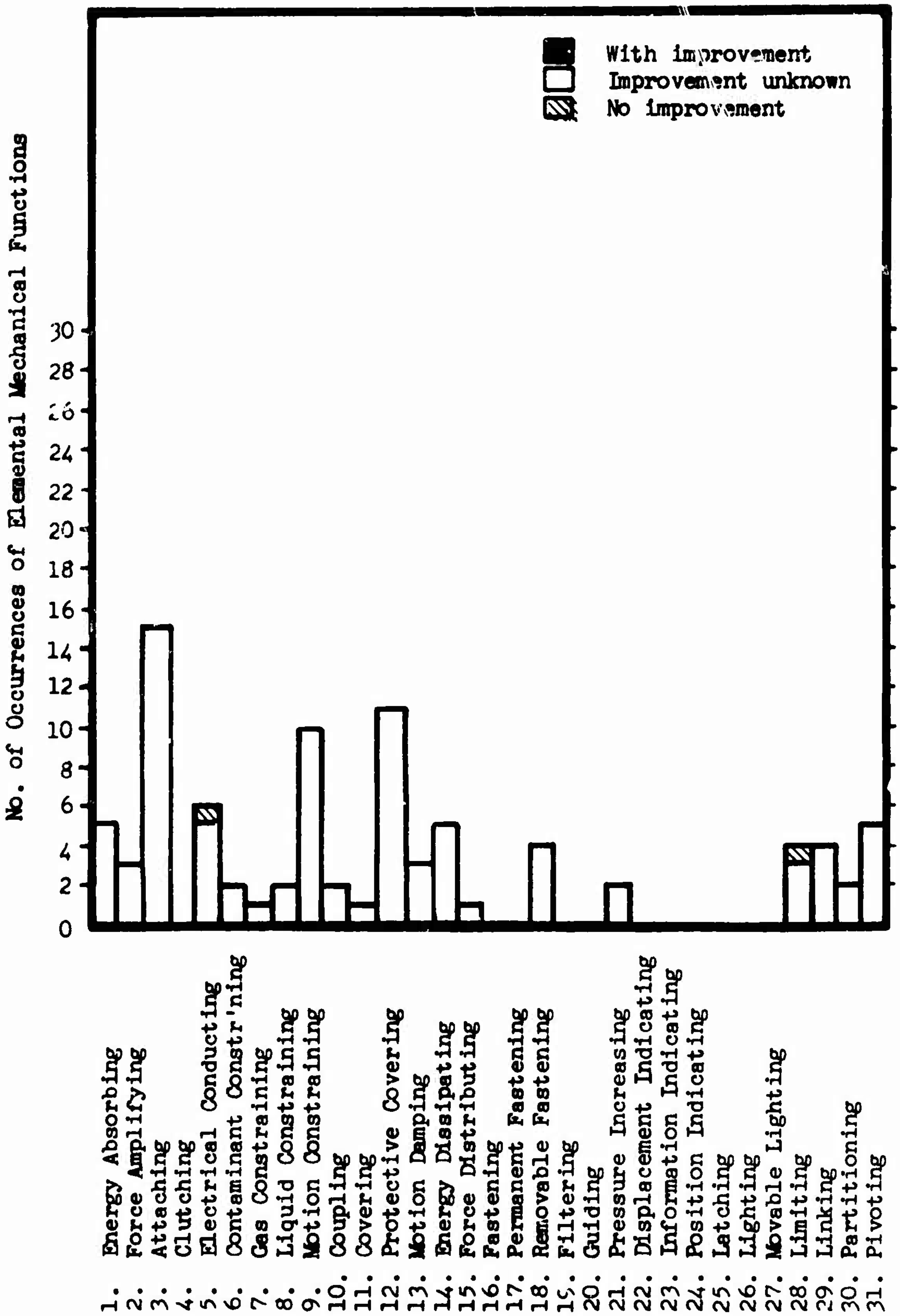


Figure 38. Frequency of Impaired Elemental Functions for the Improved Instructions to Field Personnel Corrective Action - Series II.

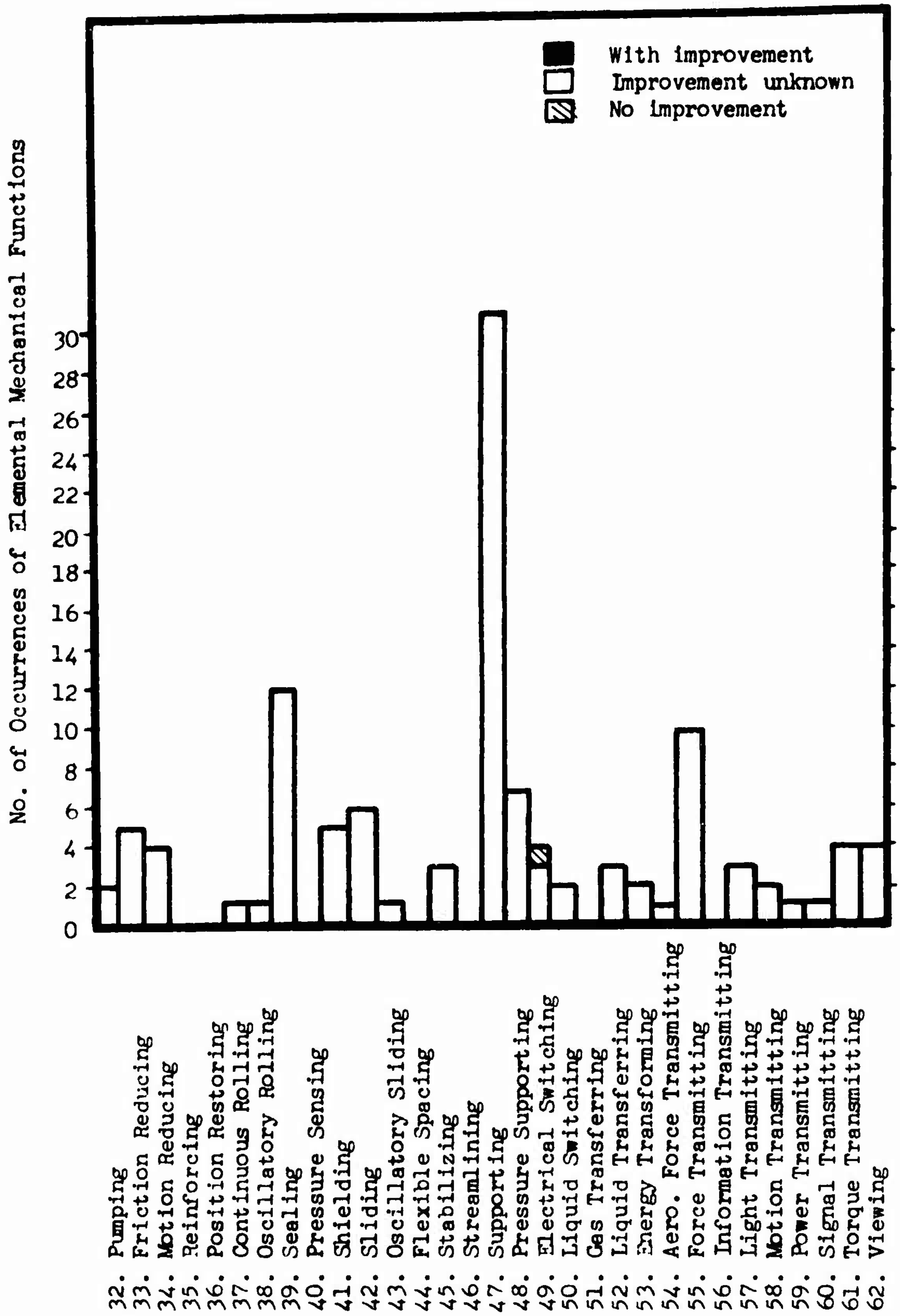


Figure 38 - Continued.

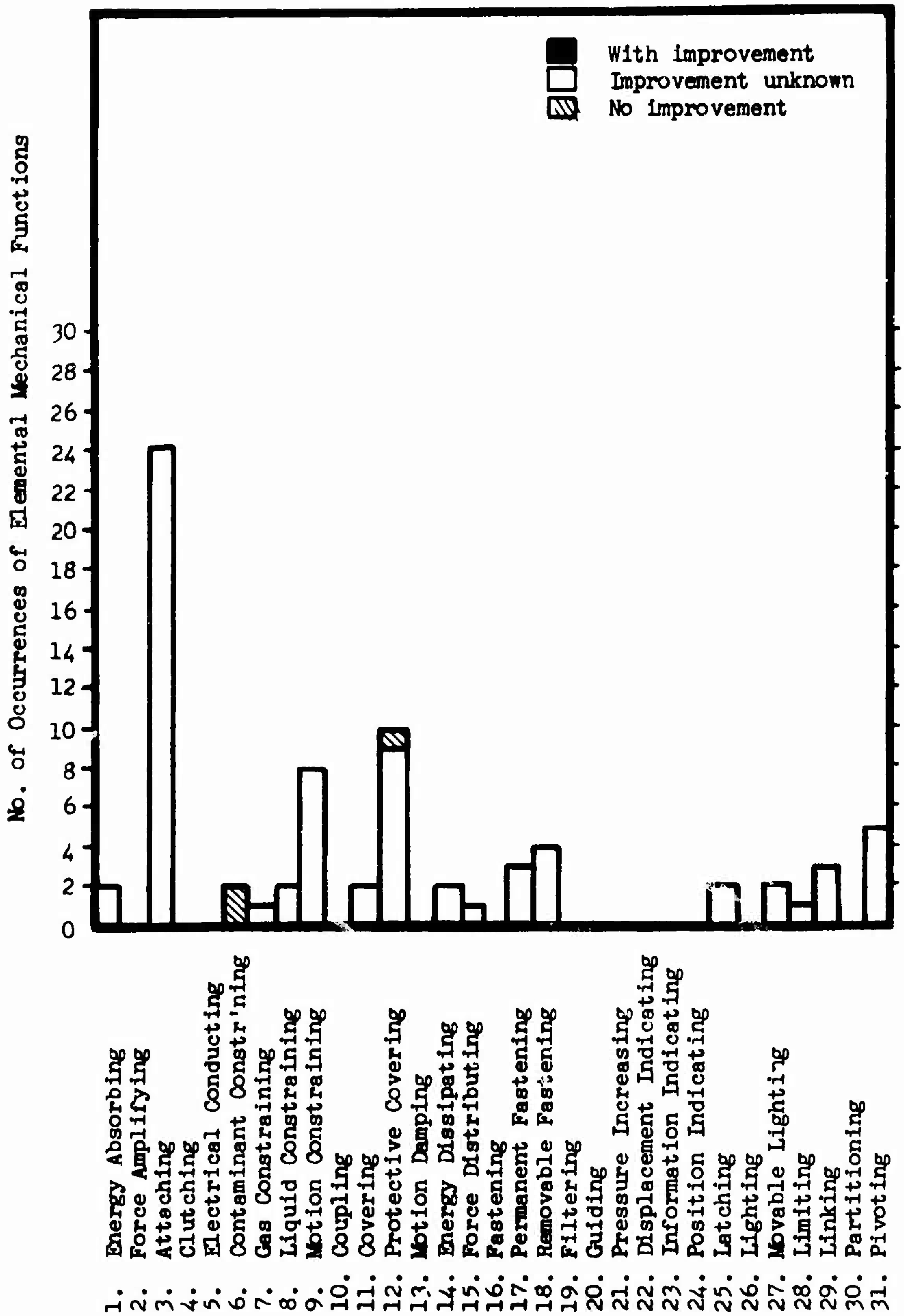


Figure 39. Frequency of Impaired Elemental Functions for the Changed Dimensions Corrective Action - Series II.

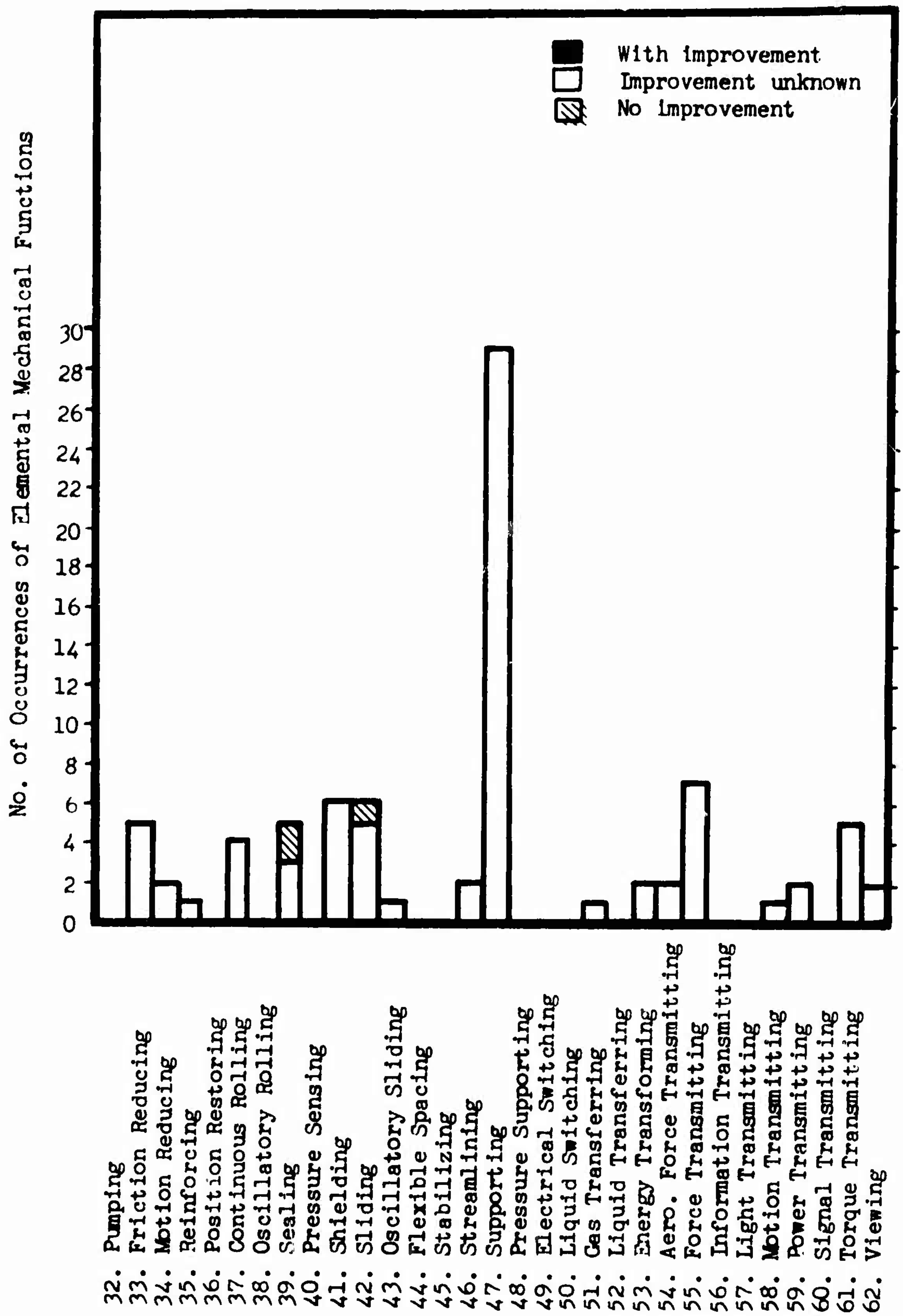


Figure 39 - Continued.

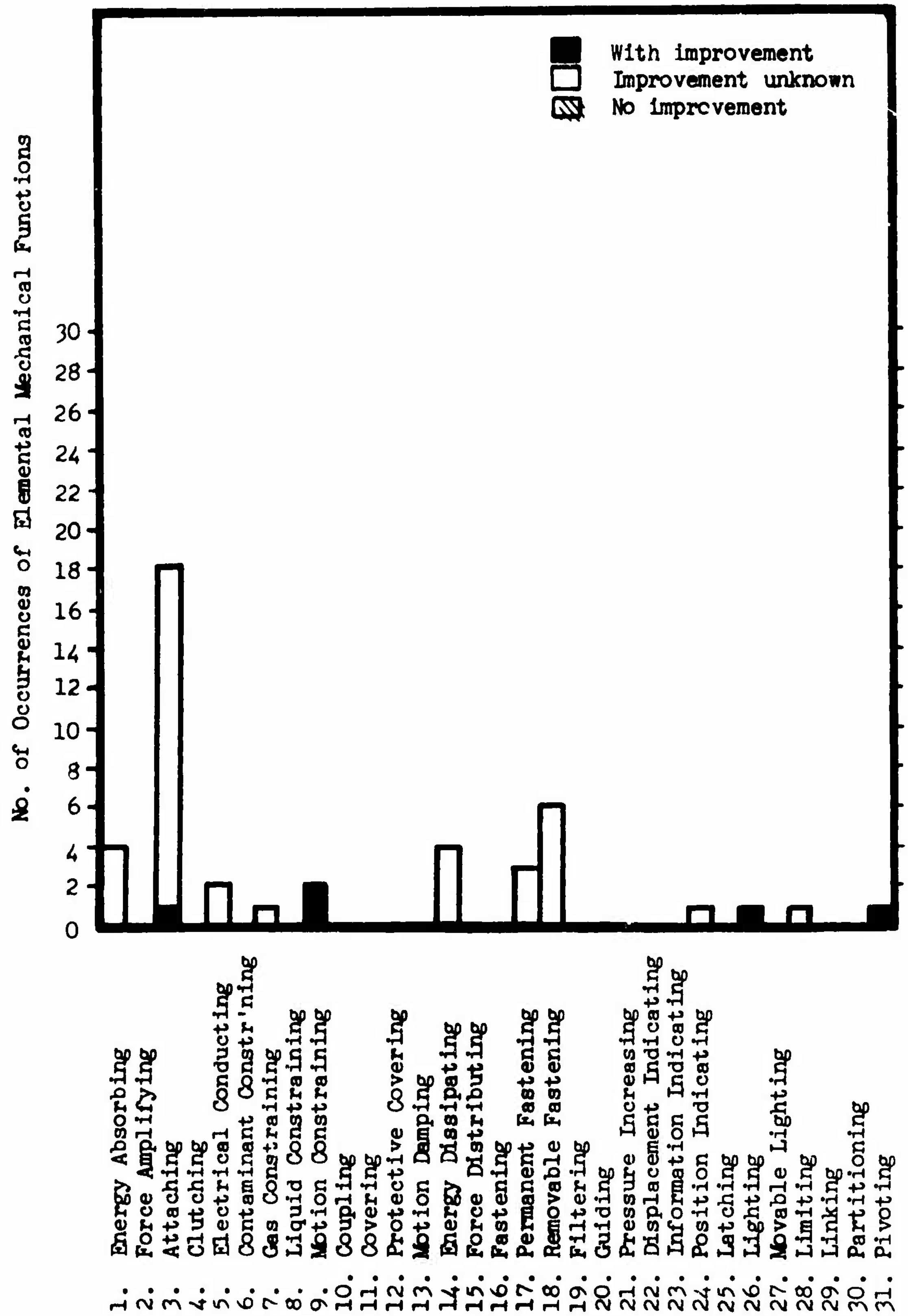


Figure 40. Frequency of Impaired Elemental Functions for the Changed Loading on Part Corrective Action - Series II.

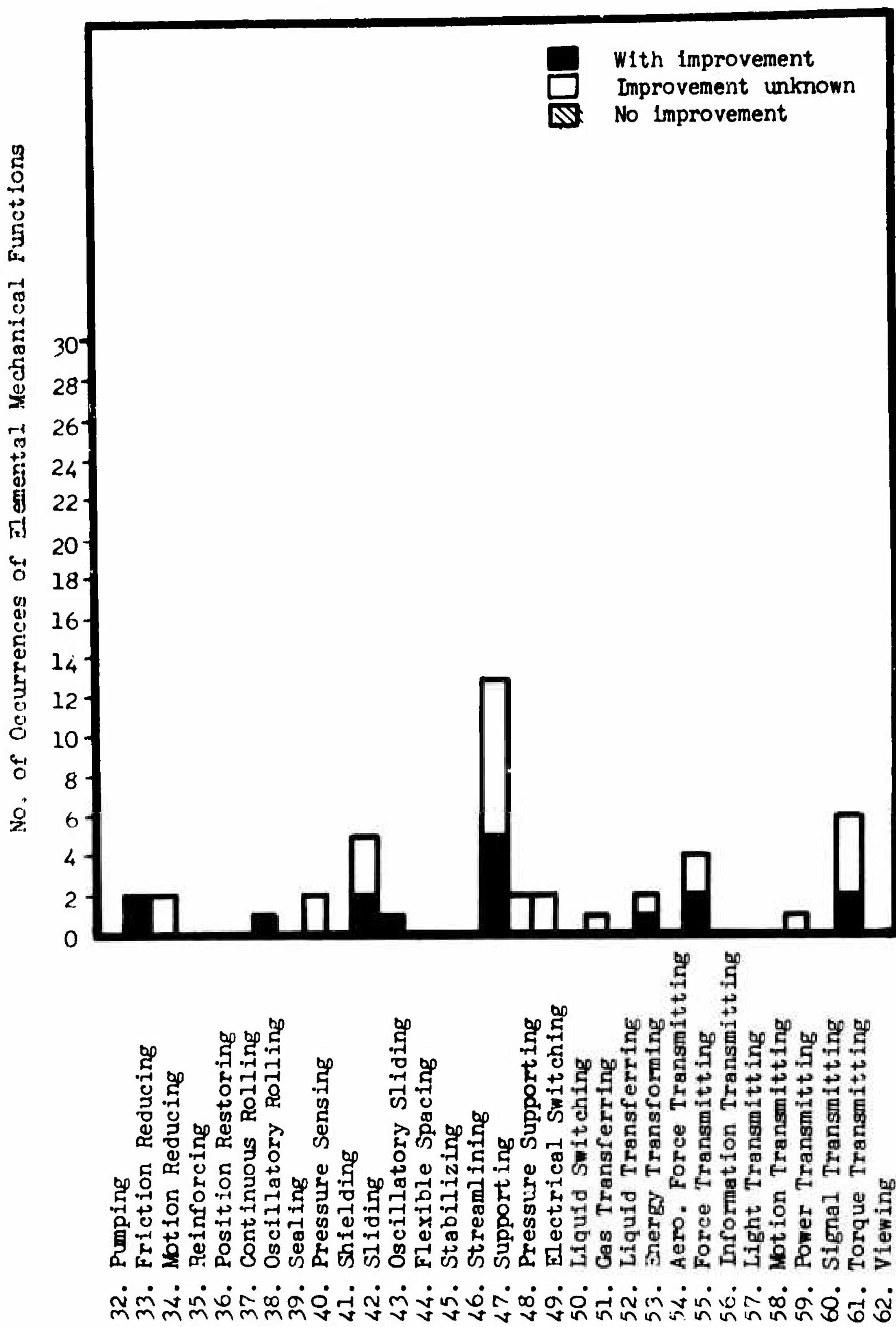


Figure 40 - Continued.

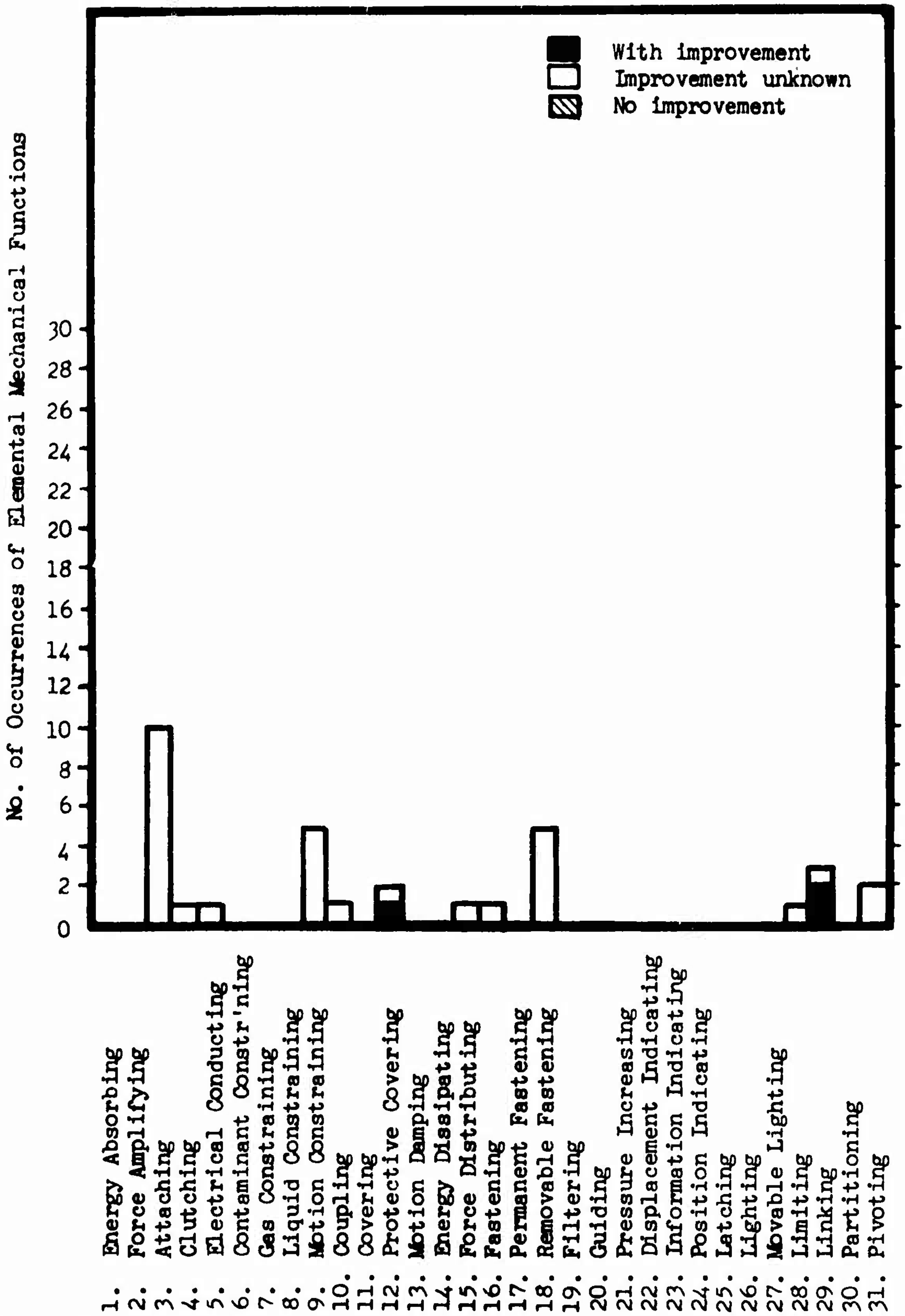


Figure 41. Frequency of Impaired Elemental Functions for the Applied Surface Coating Corrective Action - Series II.

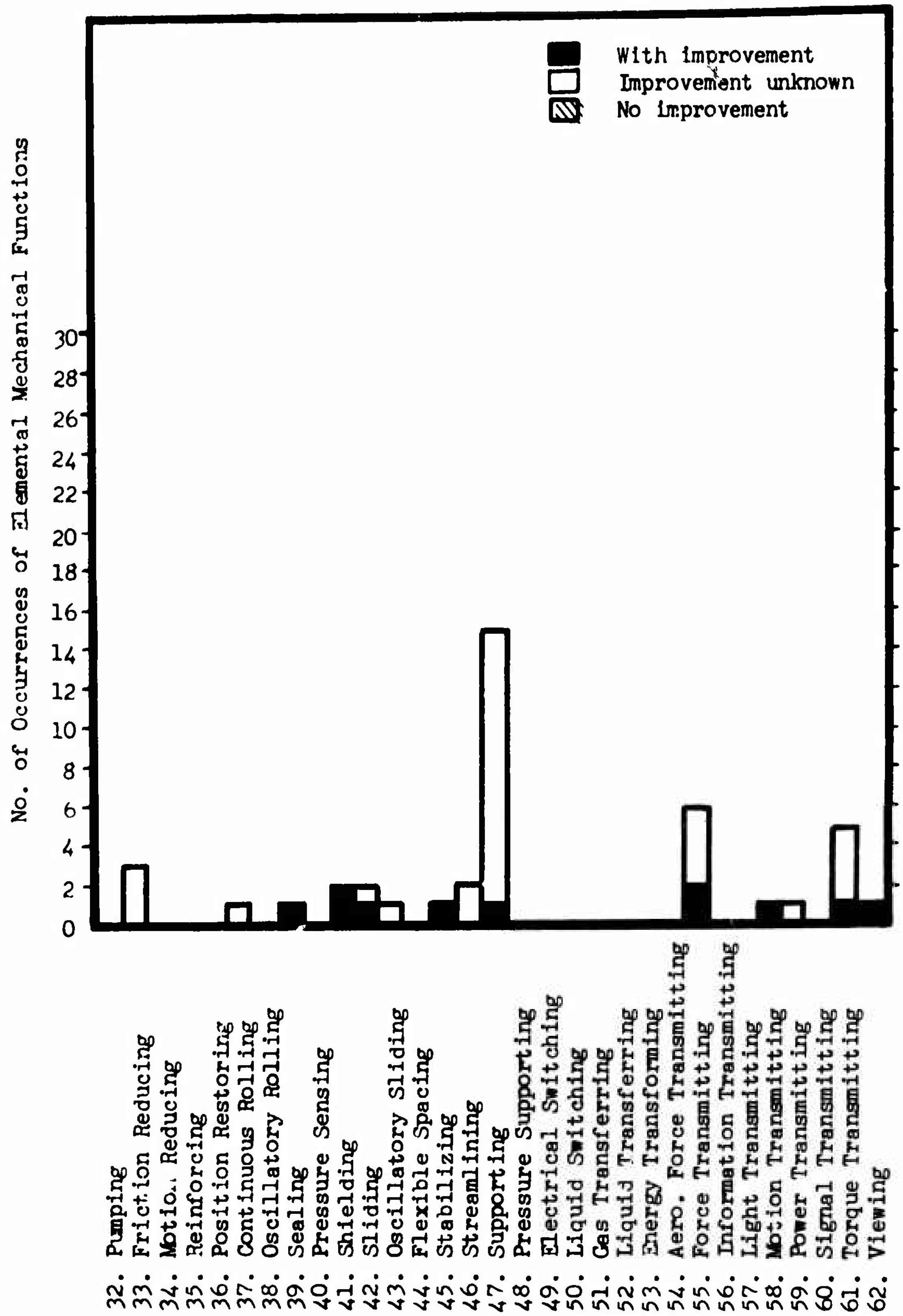


Figure 41 - Continued.

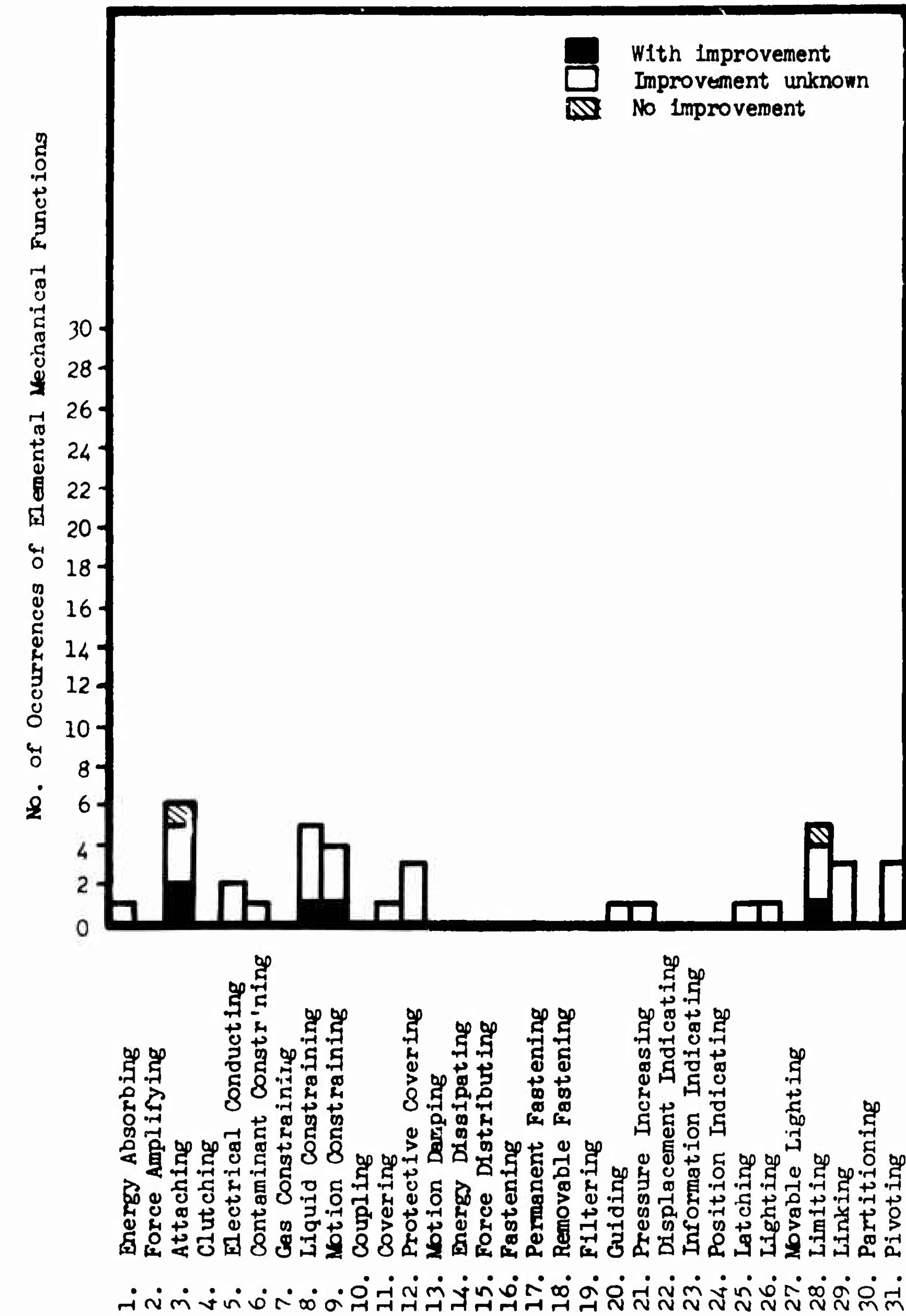
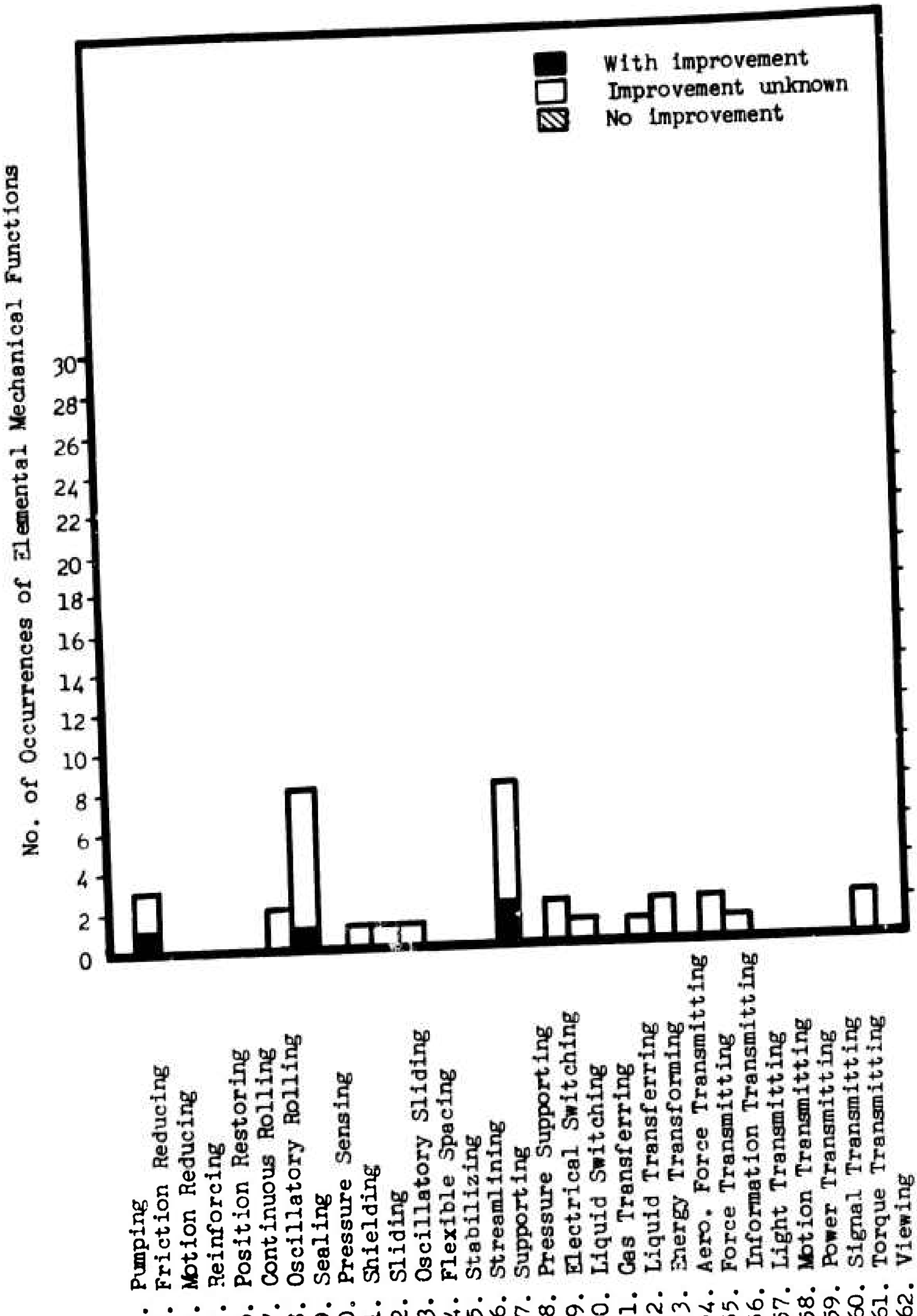


Figure 42. Frequency of Impaired Elemental Functions for the Changed Mechanism of Operation Corrective Action - Series II.



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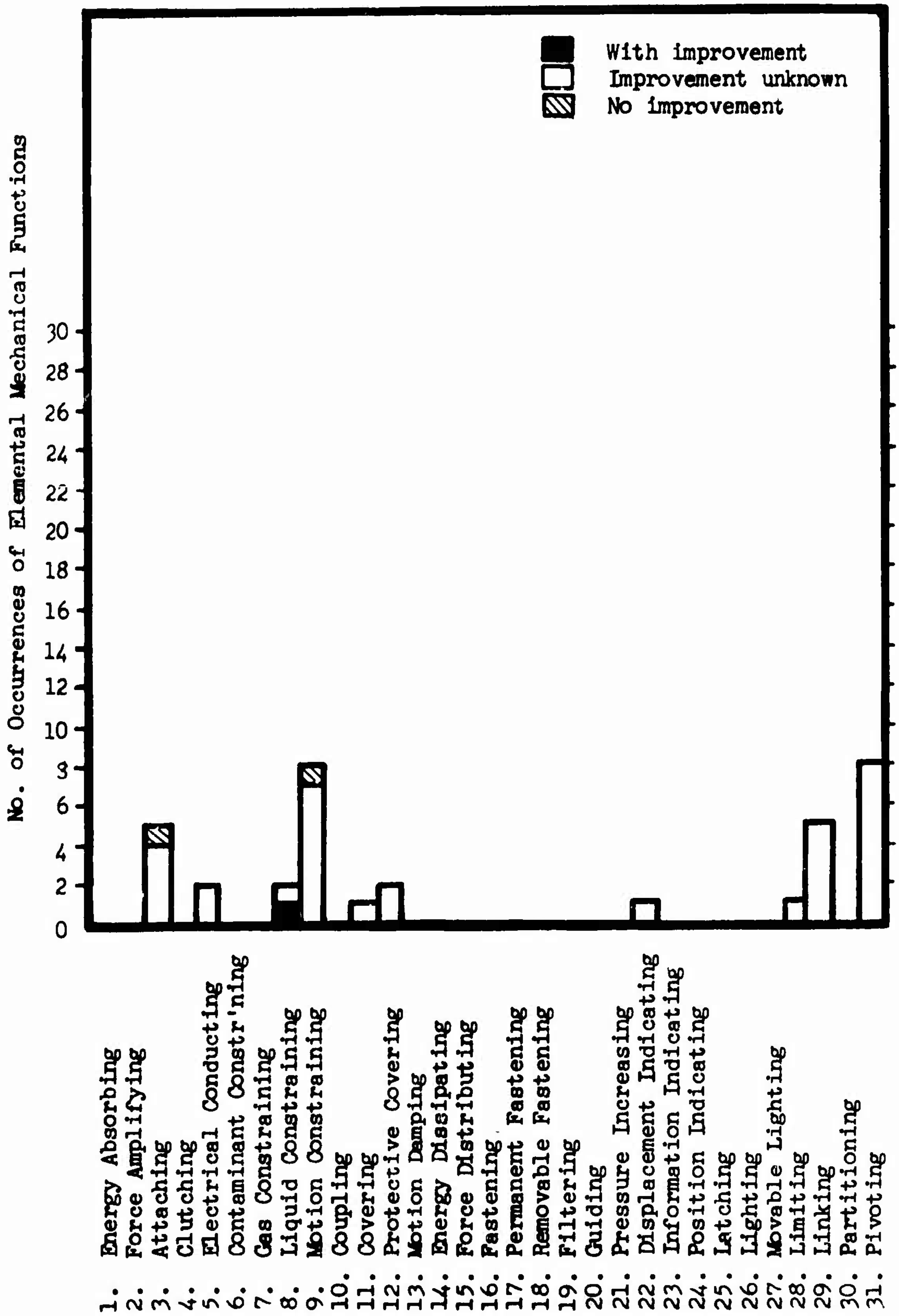


Figure 43. Frequency of Impaired Elemental Functions for the Relocated or Repositioned Part Corrective Action - Series II.

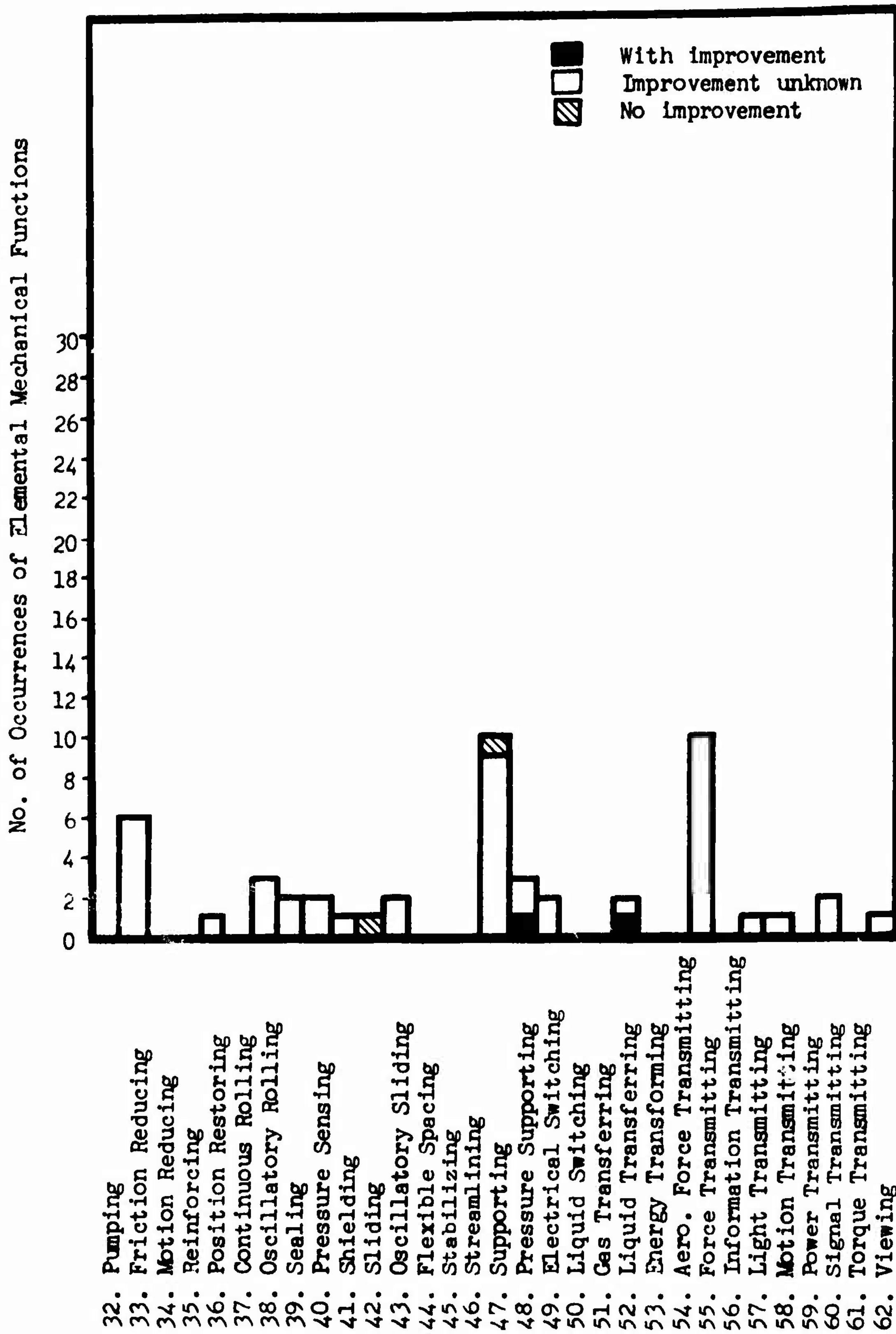


Figure 43 - Continued.

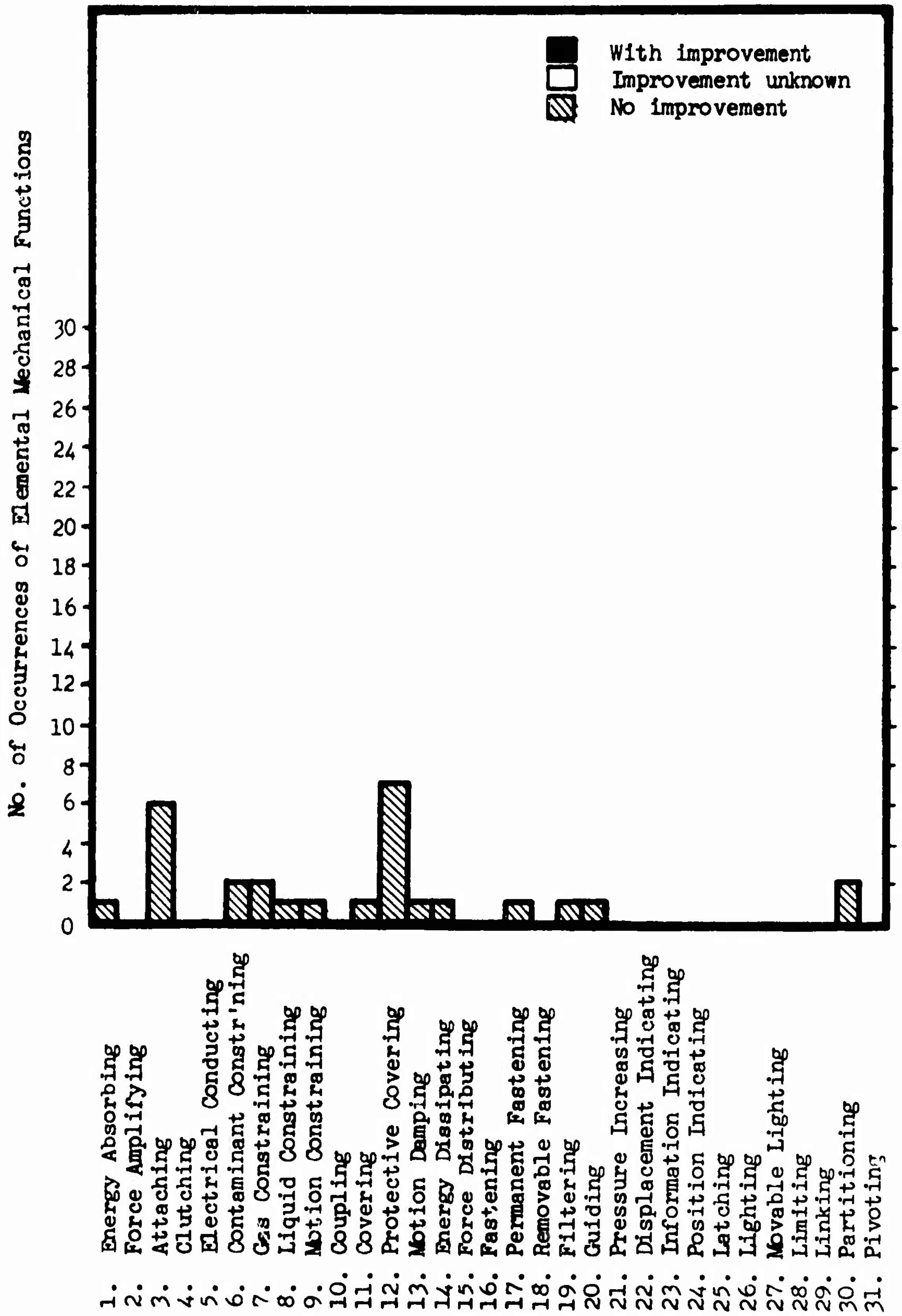


Figure 44. Frequency of Impaired Elemental Functions for the Repaired Corrective Action - Series II.

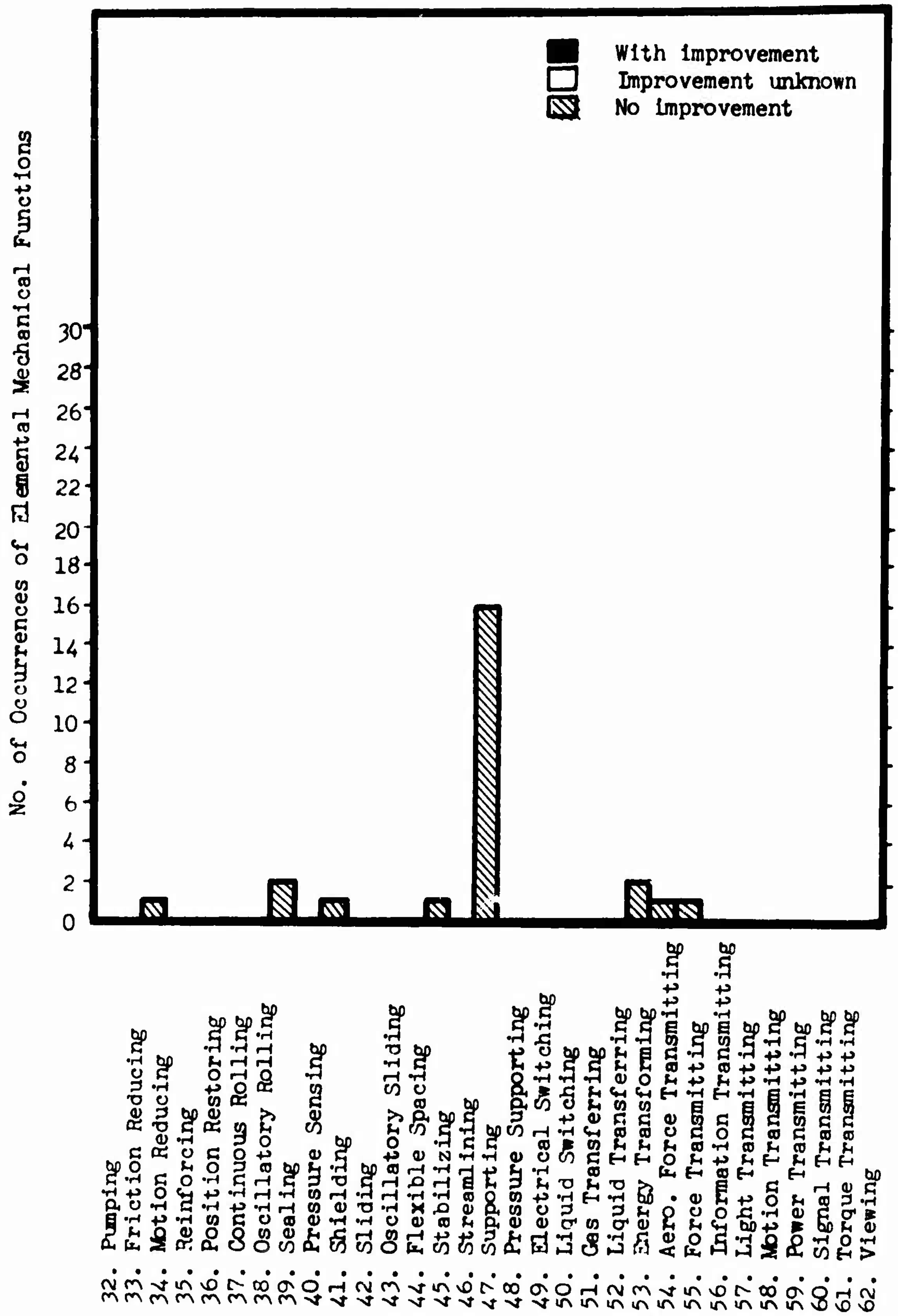


Figure 44 - Continued.

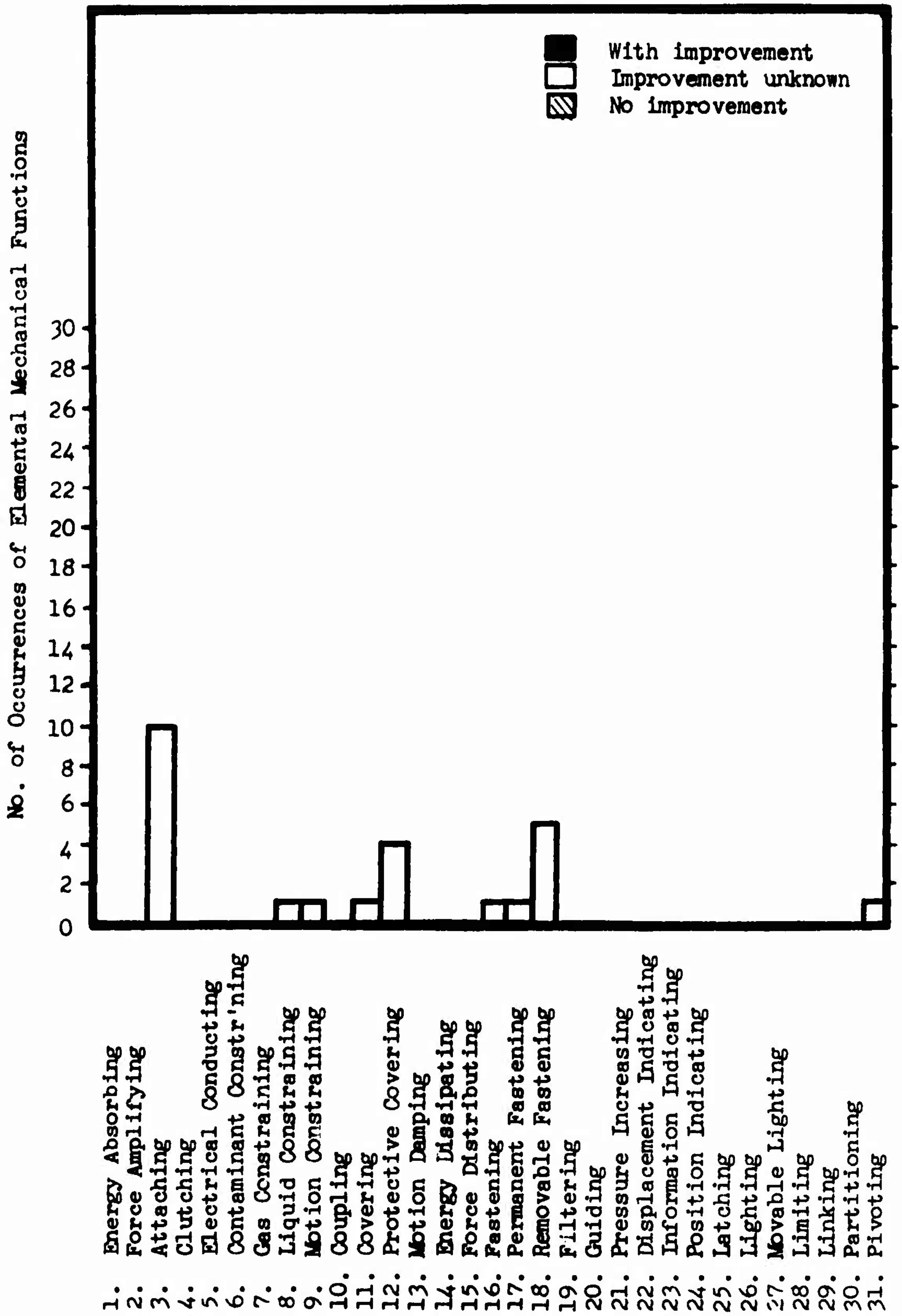
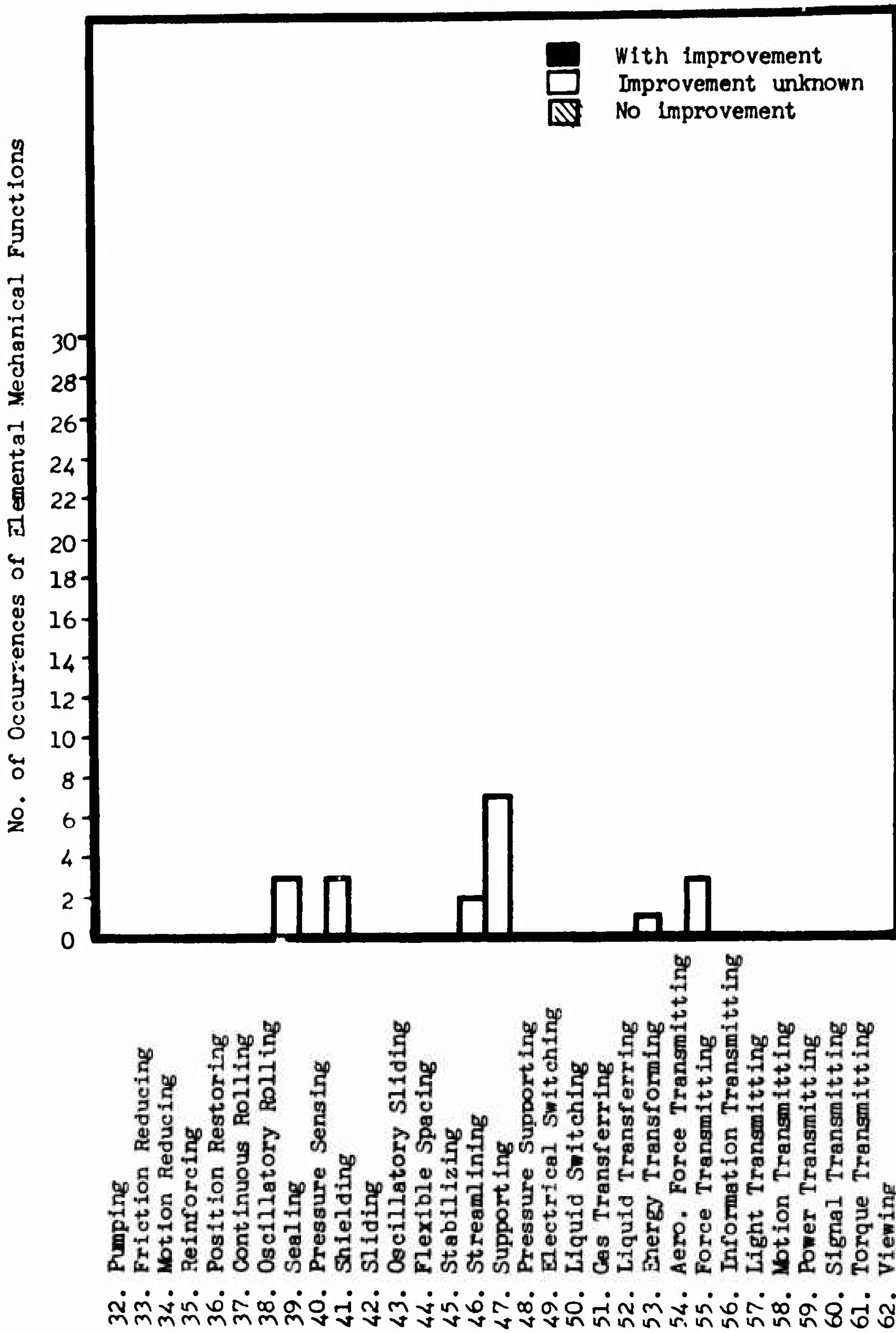


Figure 45. Frequency of Impaired Elemental Functions for the Changed Method of Attachment Corrective Action - Series II.



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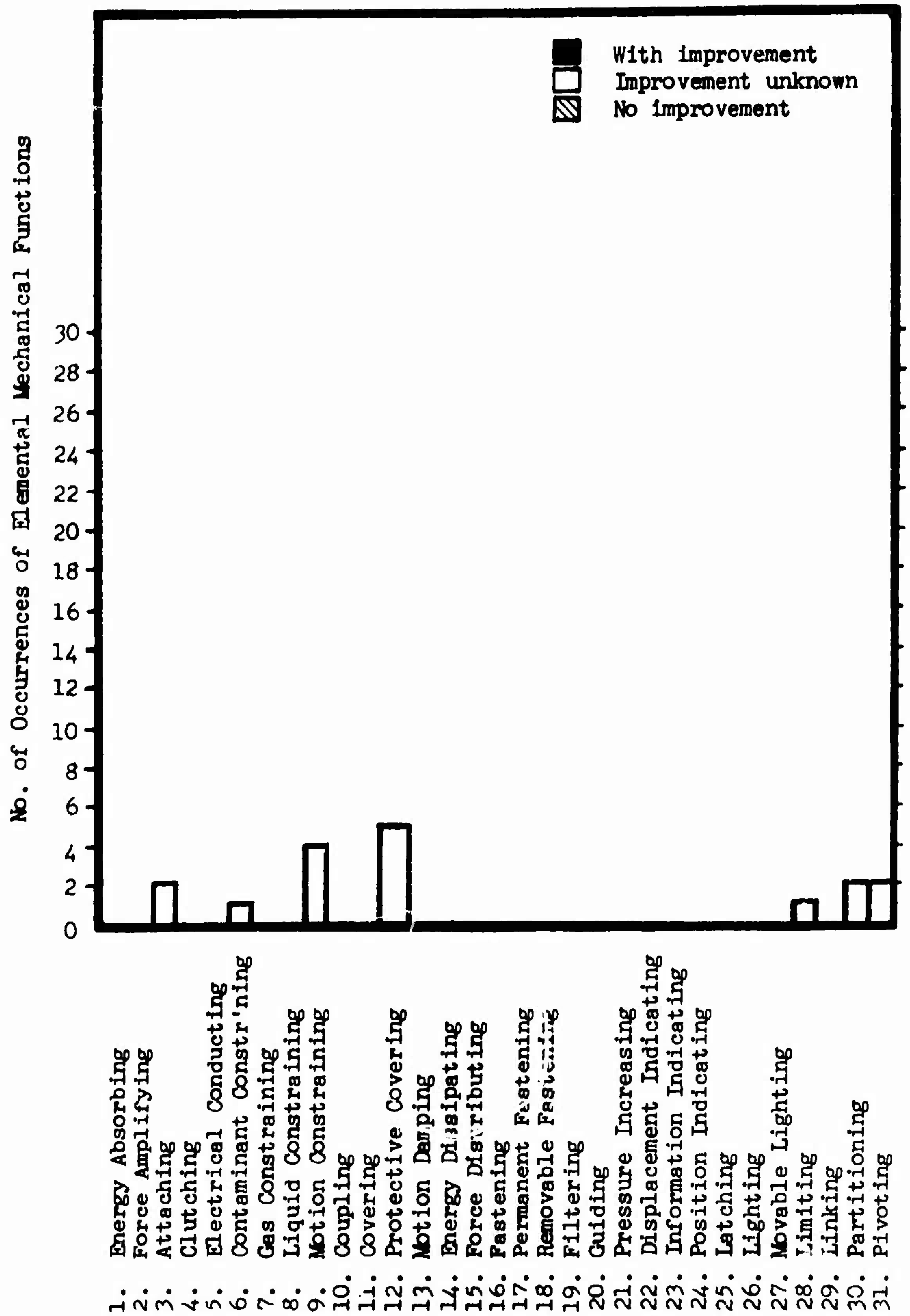


Figure 46. Frequency of Impaired Elemental Functions for the Changed Manufacturing Procedure Corrective Action - Series II.

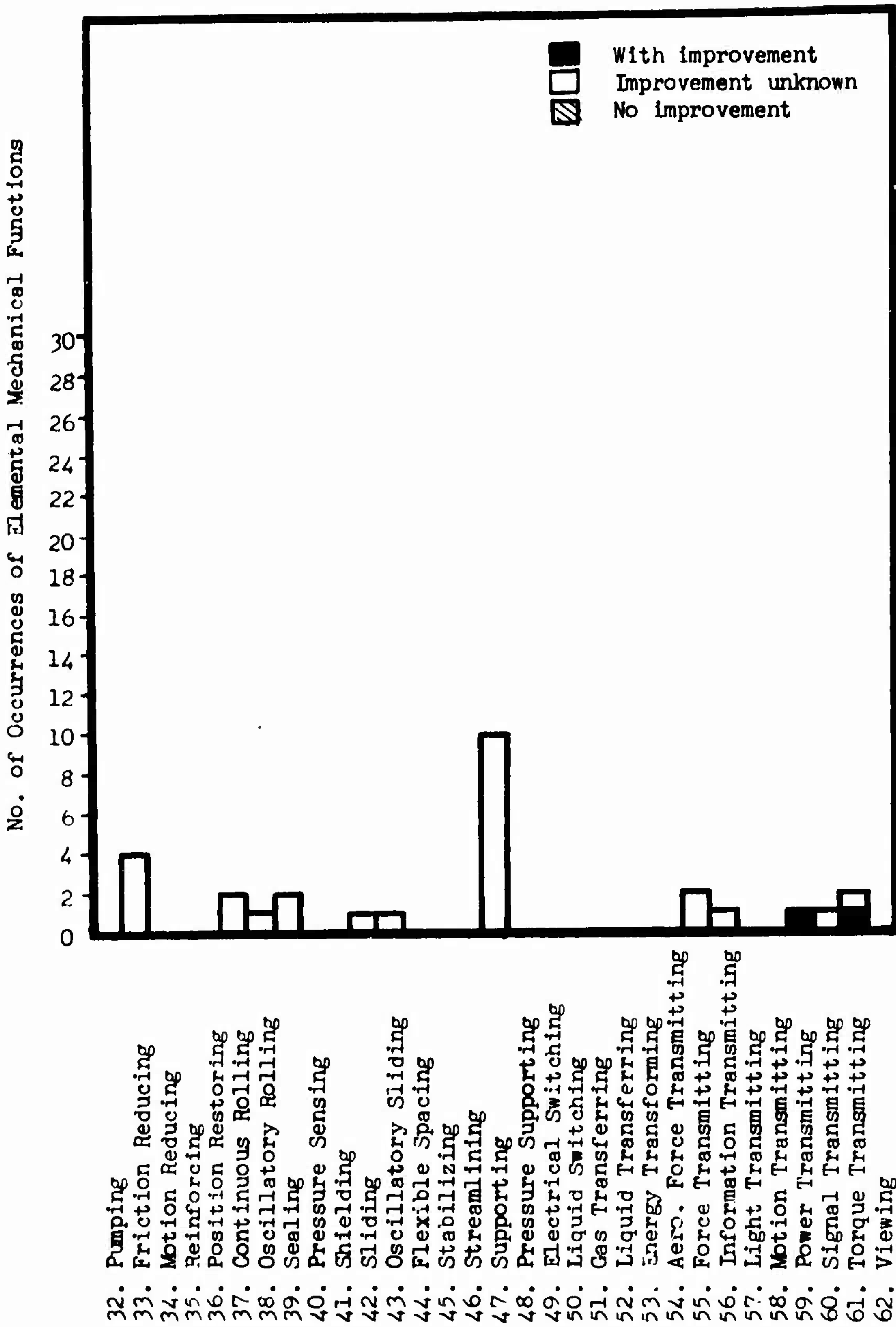


Figure 46 - Continued.

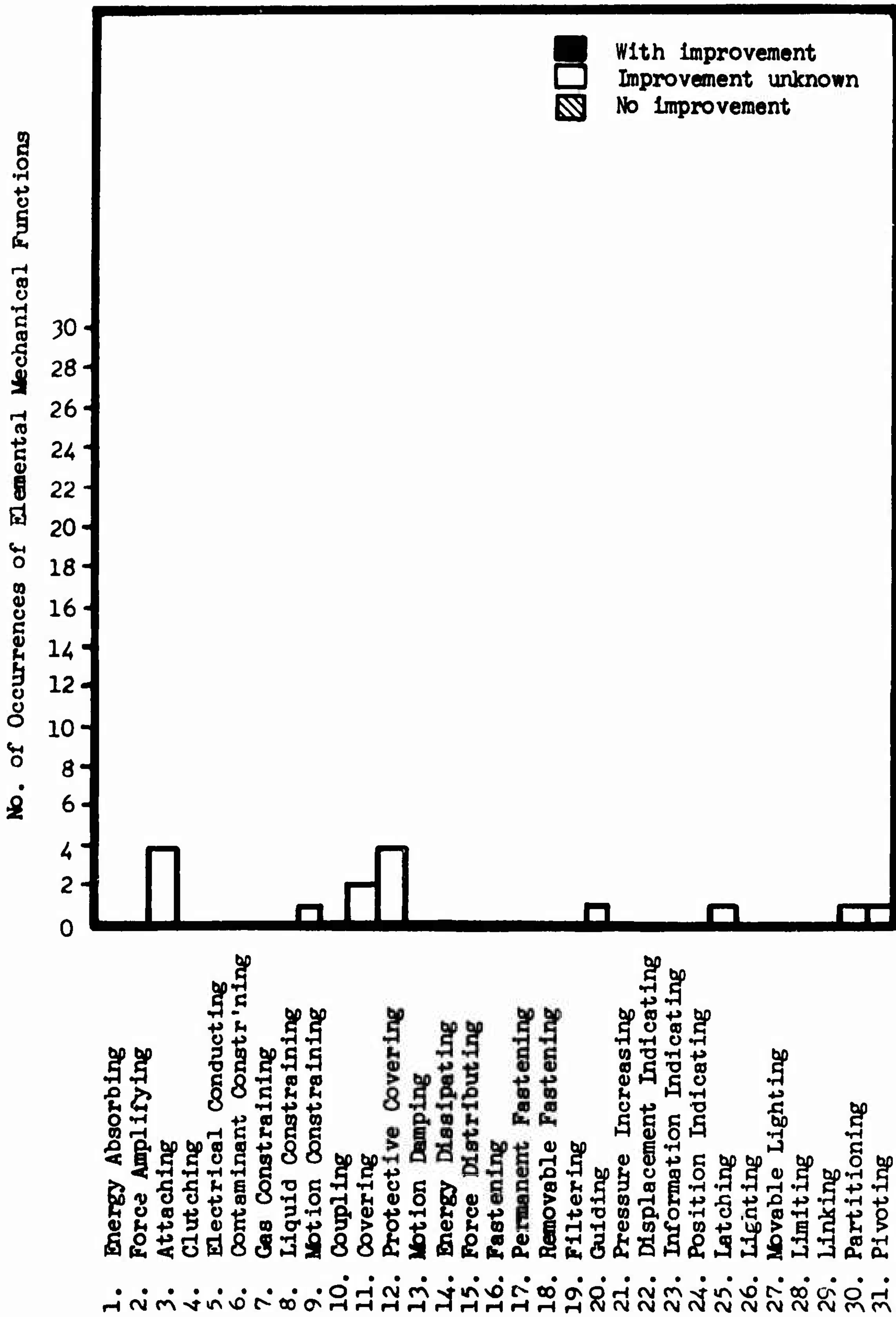
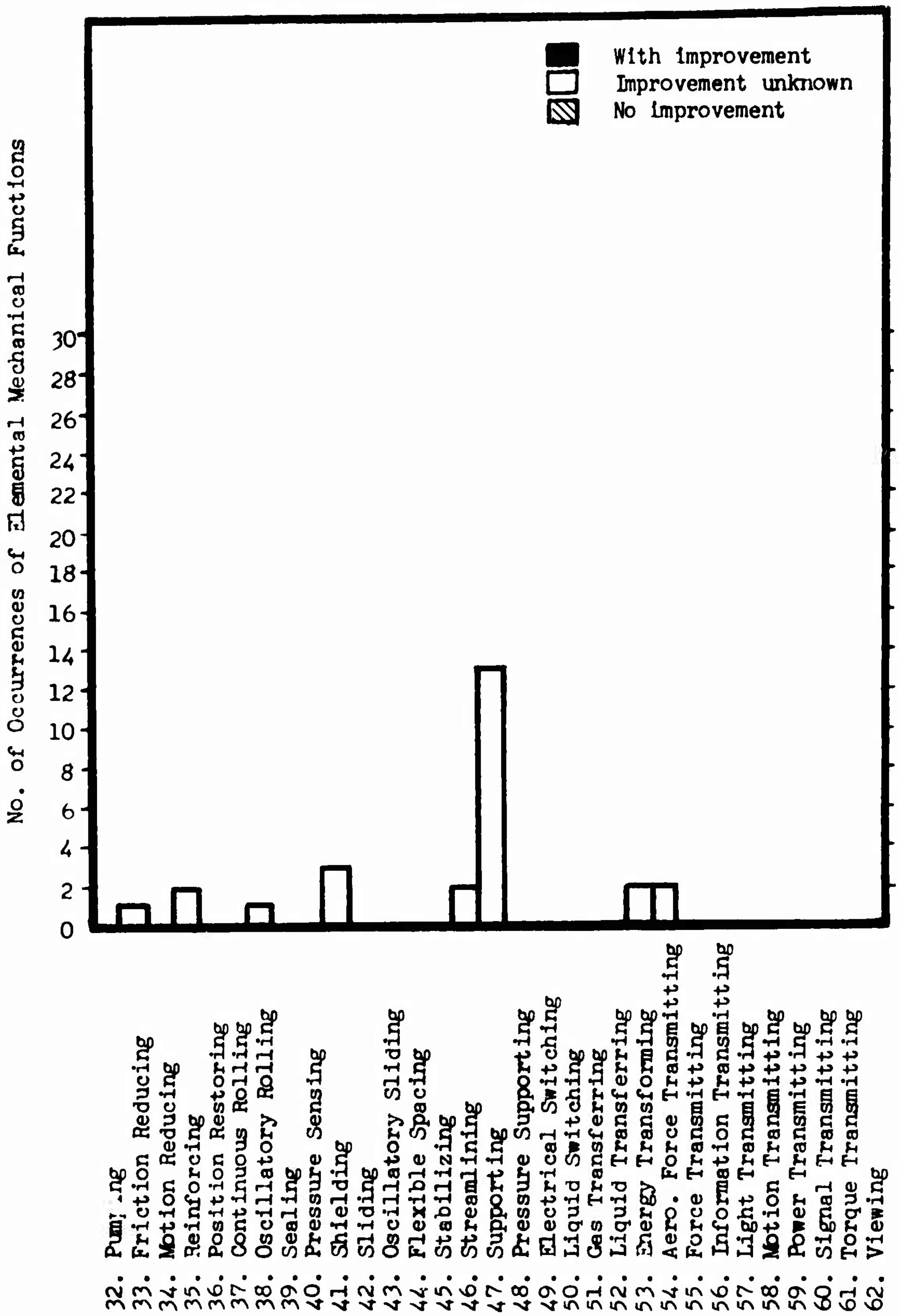


Figure 47. Frequency of Impaired Elemental Functions for the Reinforced Part Corrective Action - Series II.



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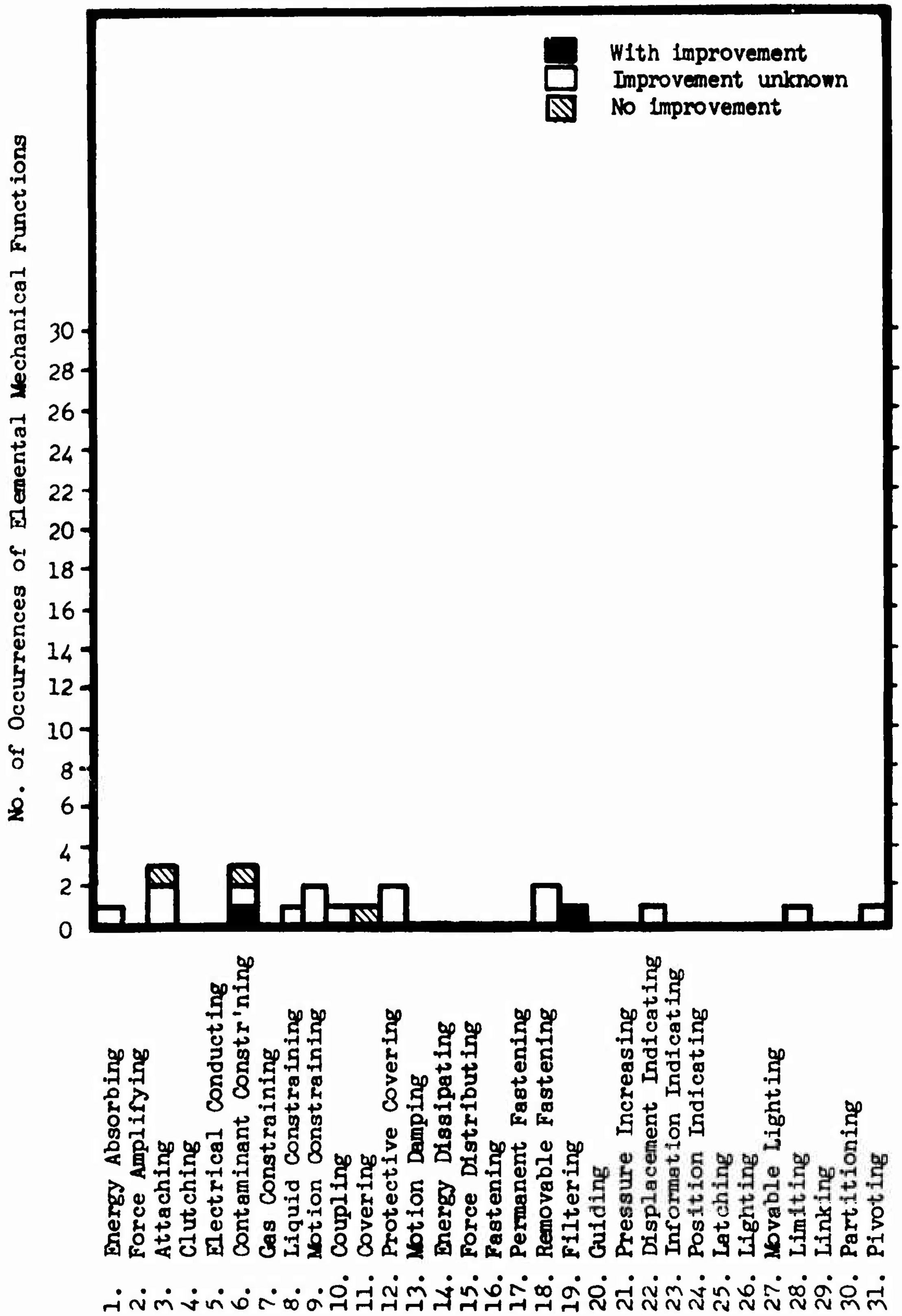


Figure 48. Frequency of Impaired Elemental Functions for the Eliminated Part Corrective Action - Series II.

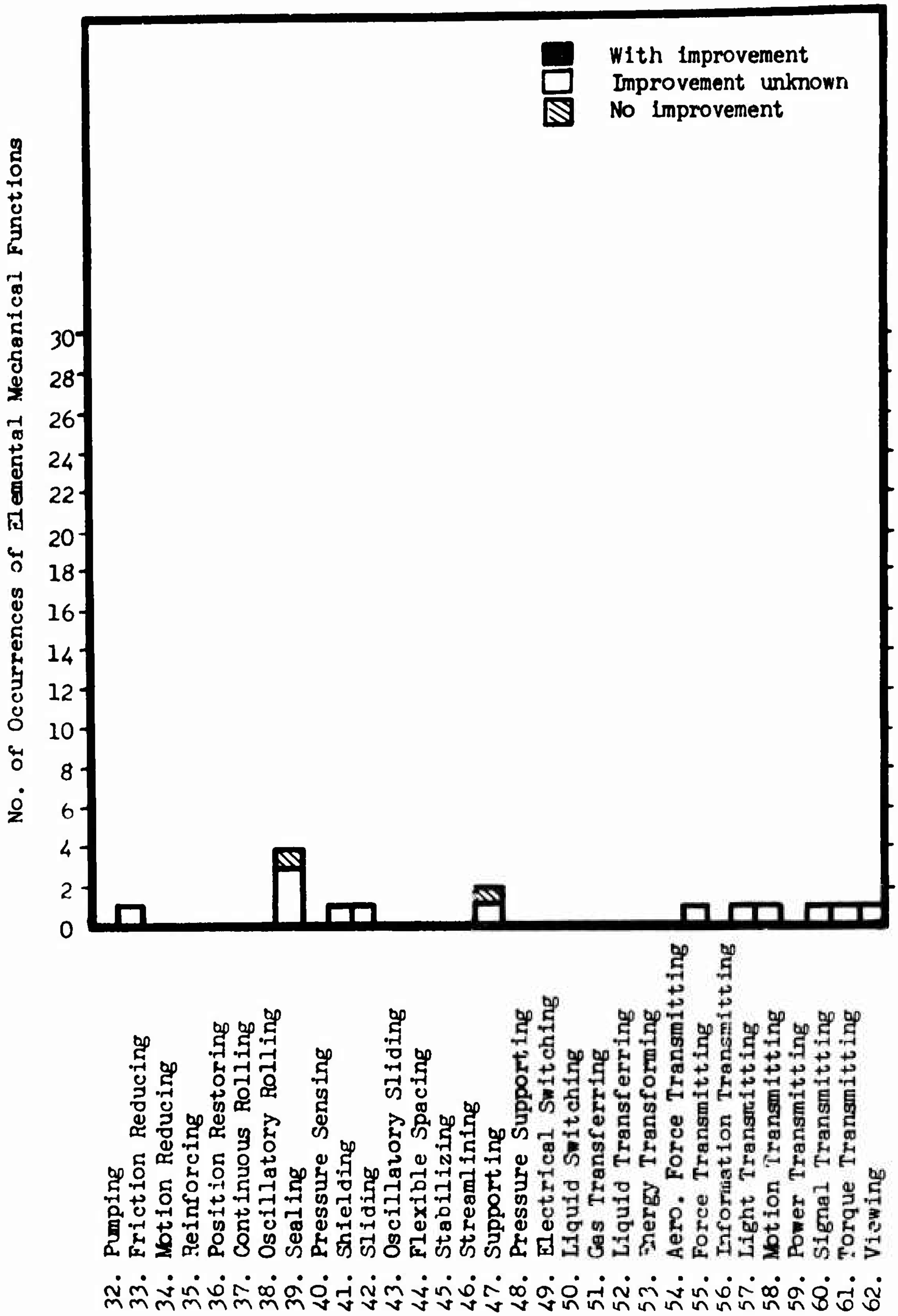


Figure 48 - Continued.

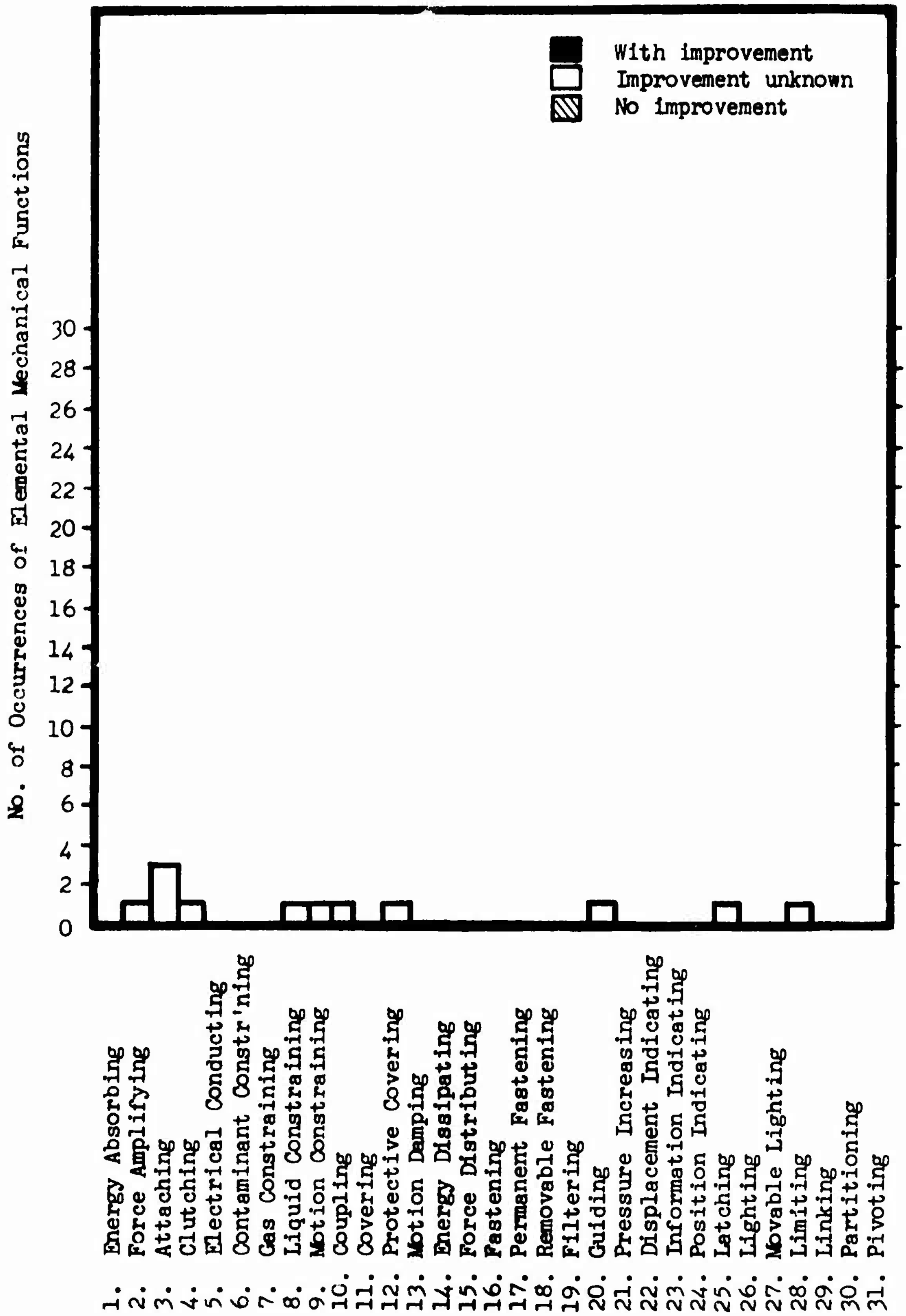
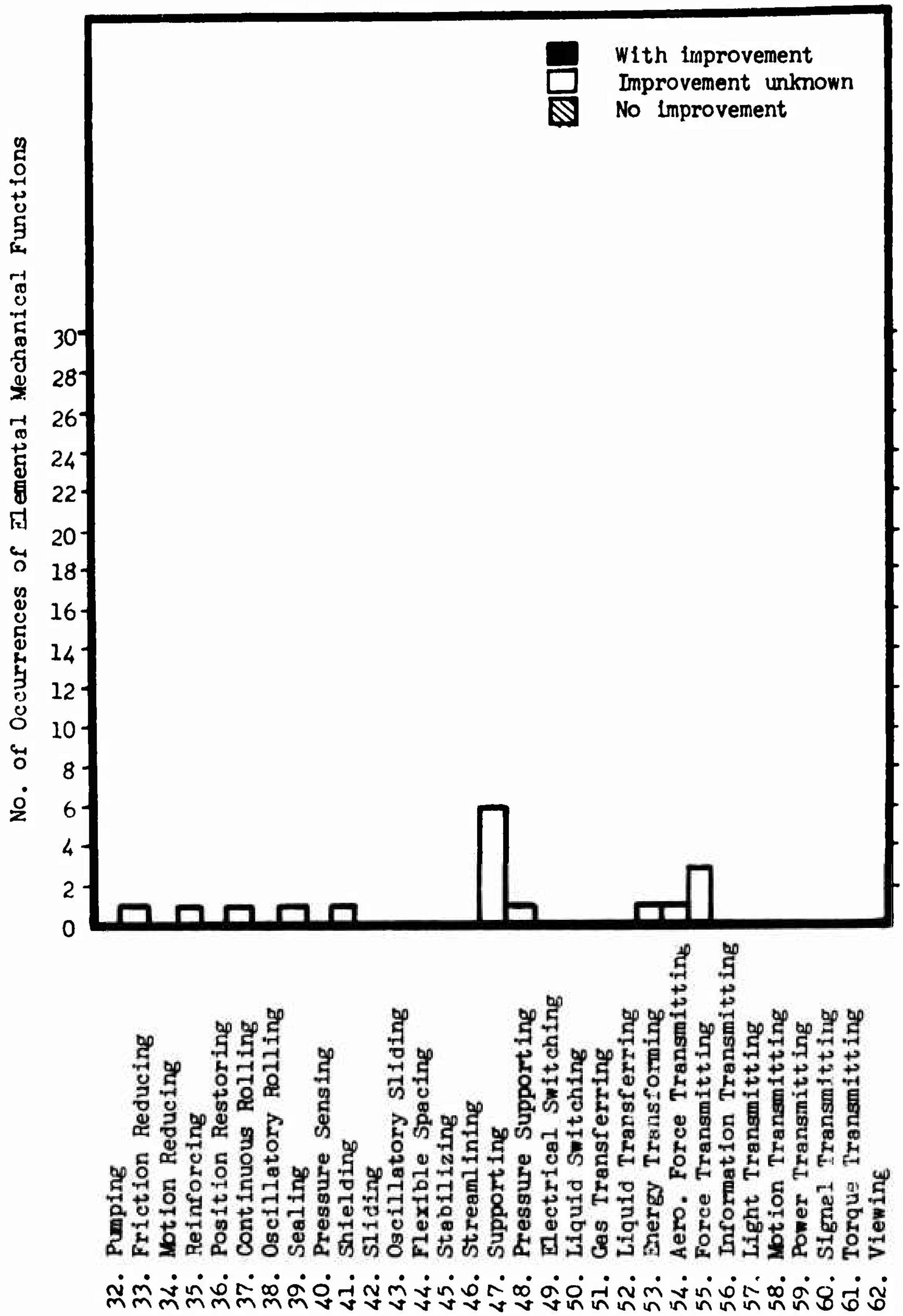


Figure 49. Frequency of Impaired Elemental Functions for the <u>Strengthened Part</u> Corrective Action - Series II.



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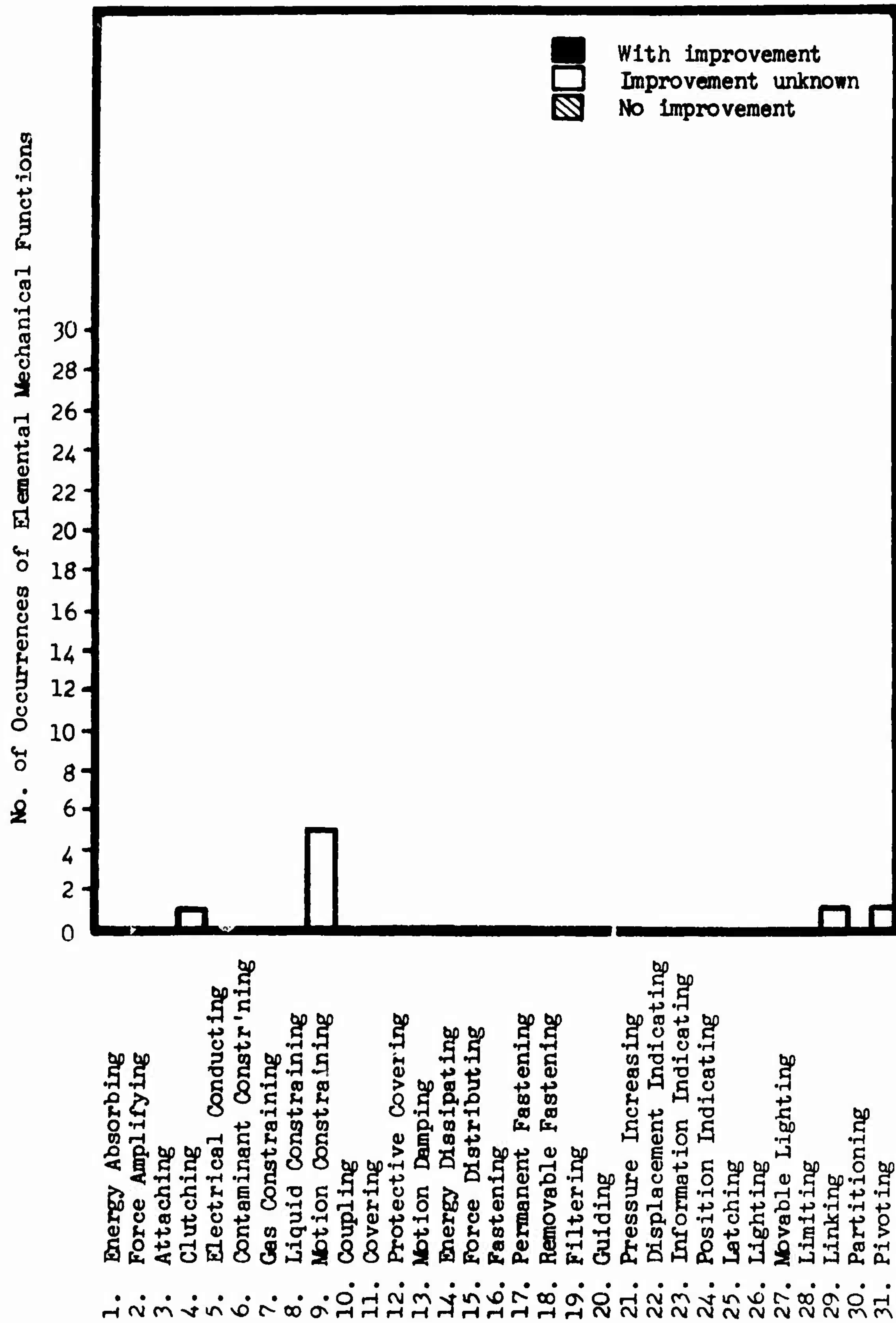
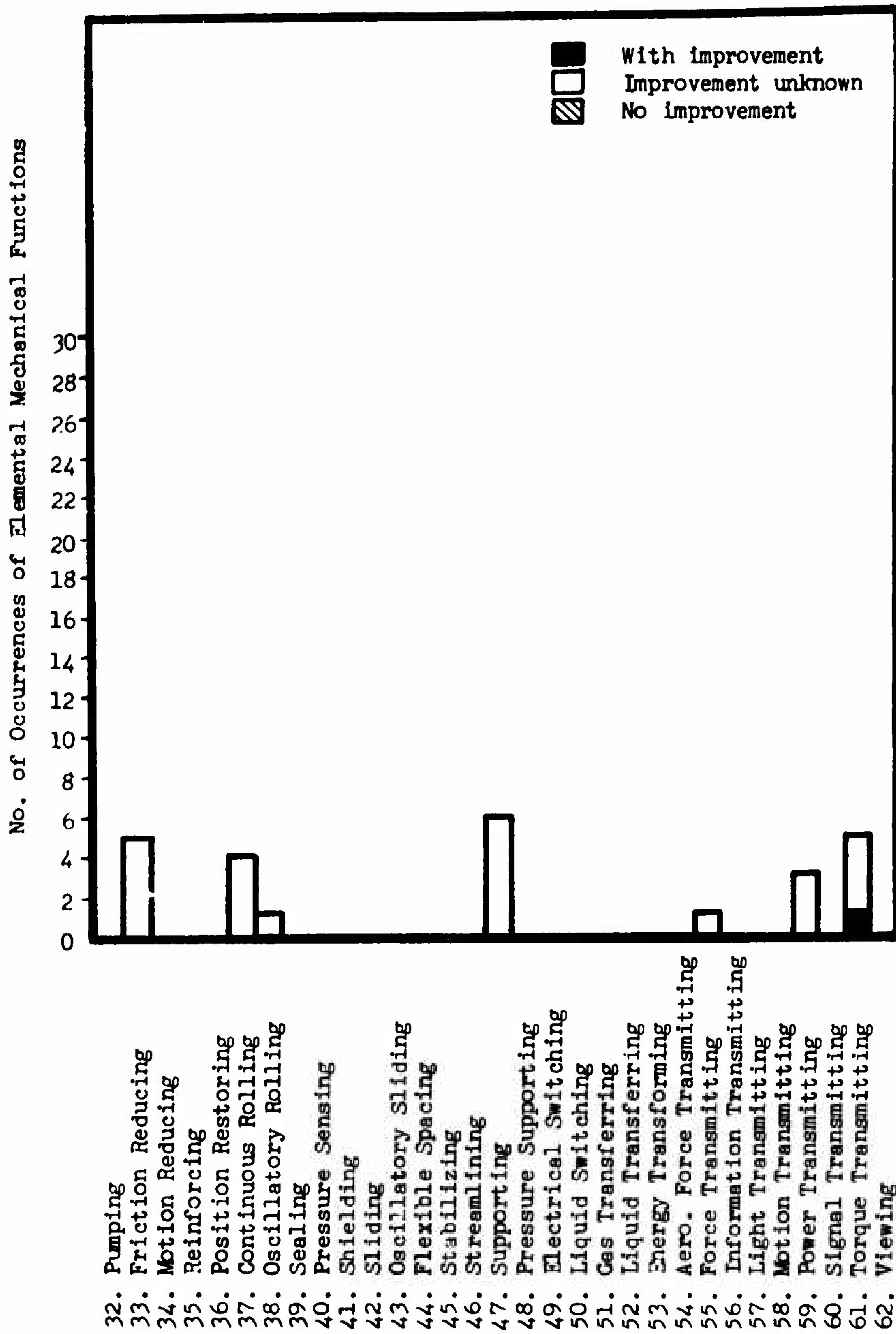


Figure 50. Frequency of Impaired Elemental Functions for the Changed Method/Frequency of Lubrication Corrective Action -Series II.



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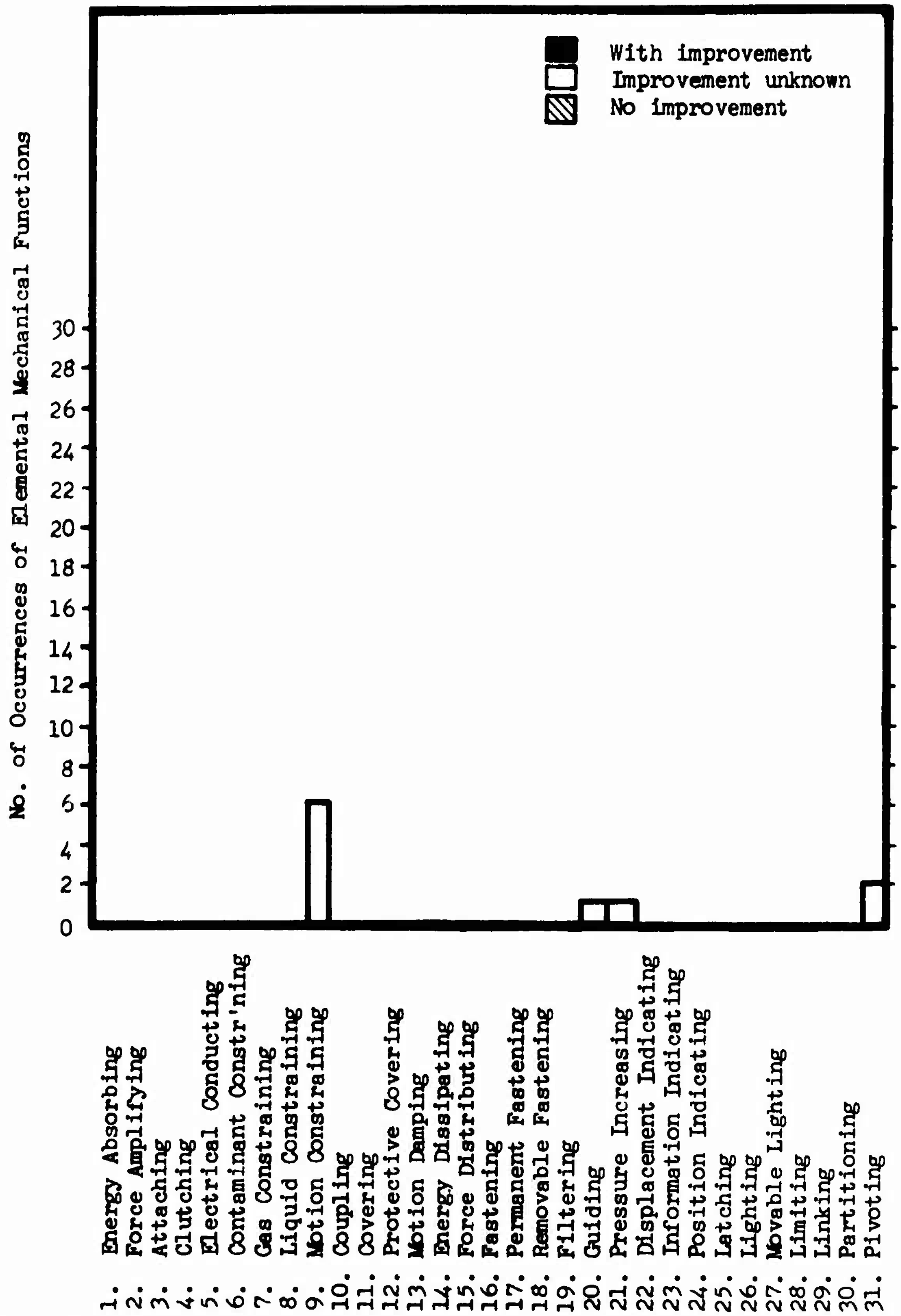


Figure 51. Frequency of Impaired Elemental Functions for the Changed Vendor Corrective Action - Series II.

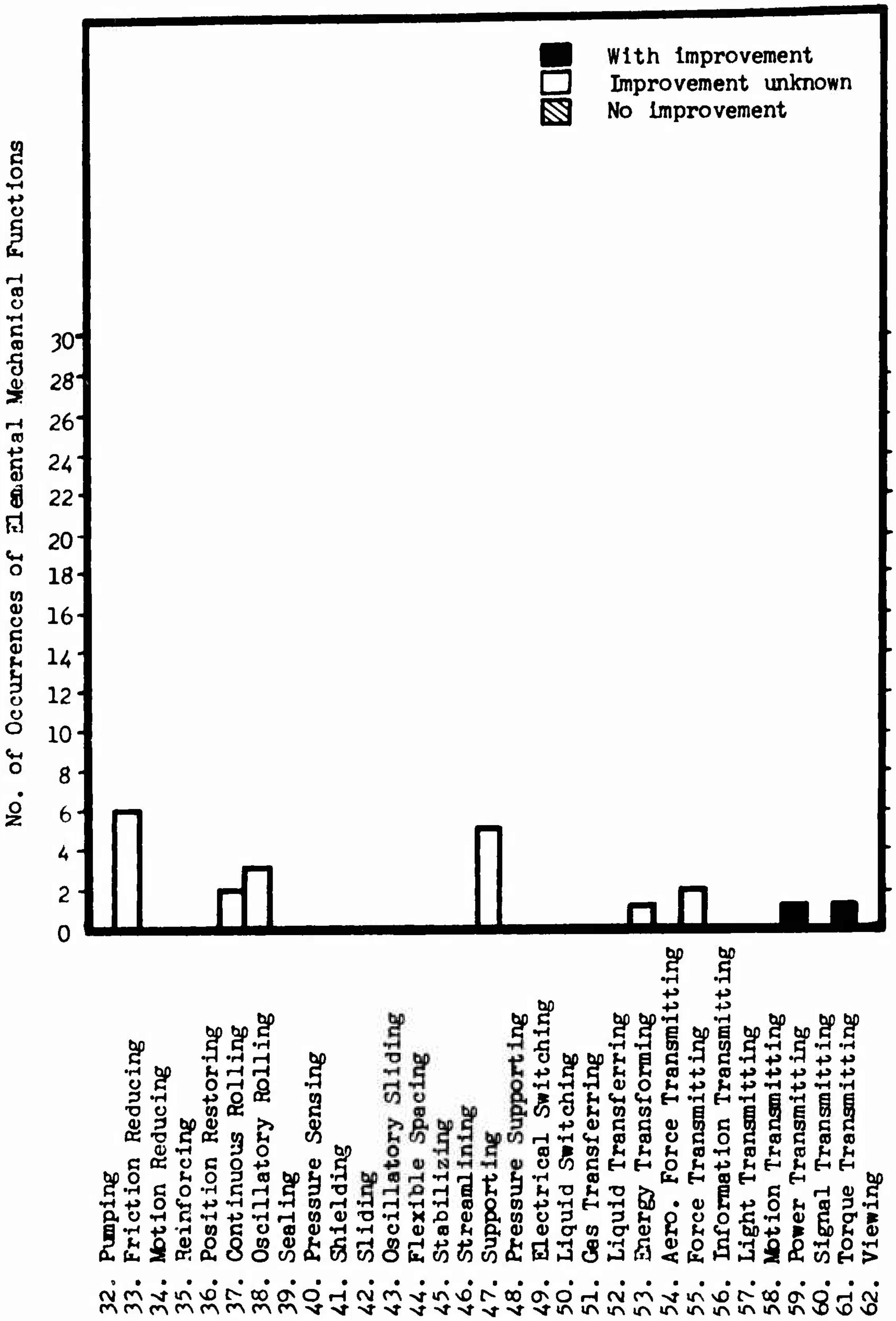


Figure 51 - Continued.

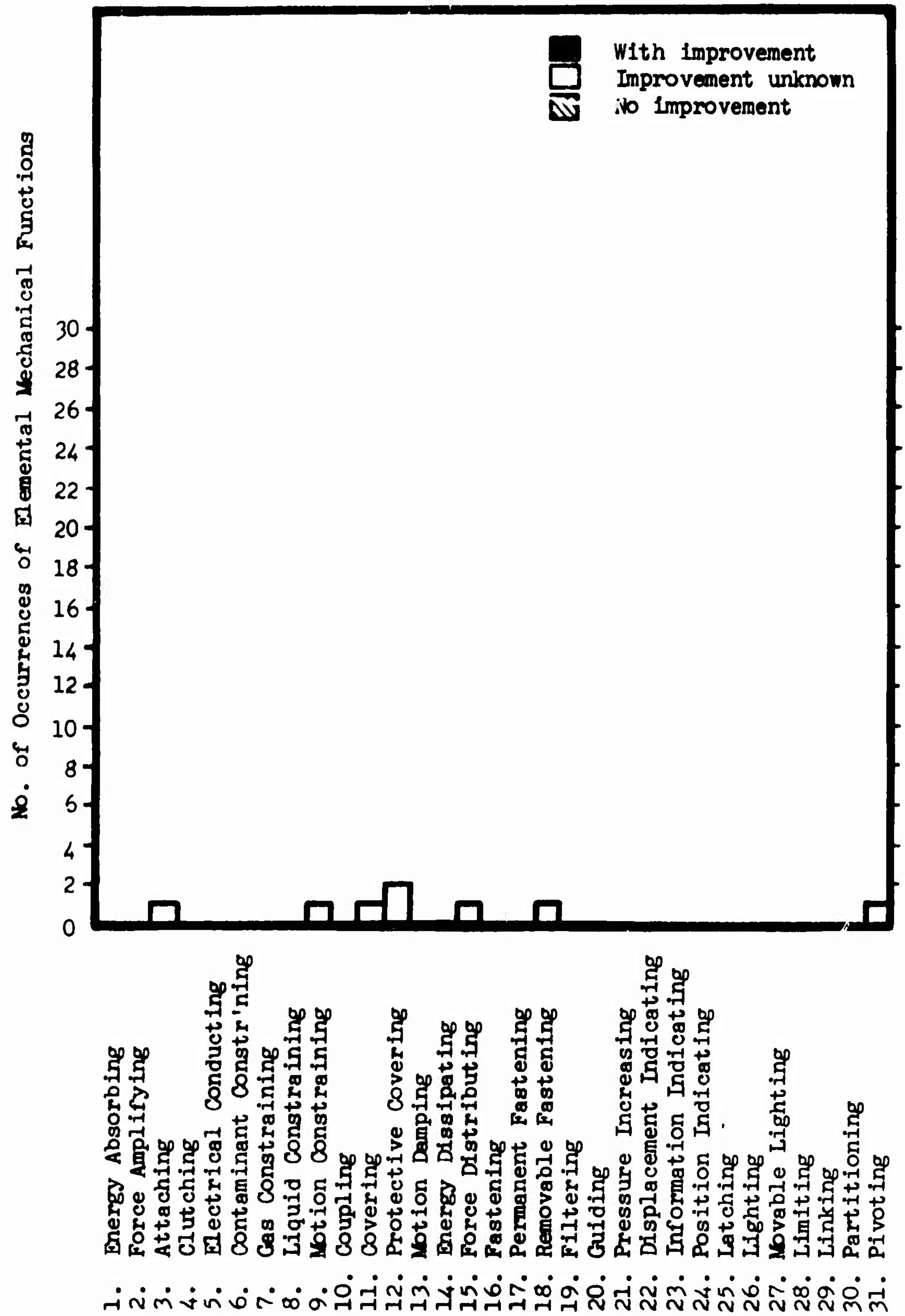


Figure 52. Frequency of Impaired Elemental Functions for the Added or Changed Adhesive Material Corrective Action - Series II.

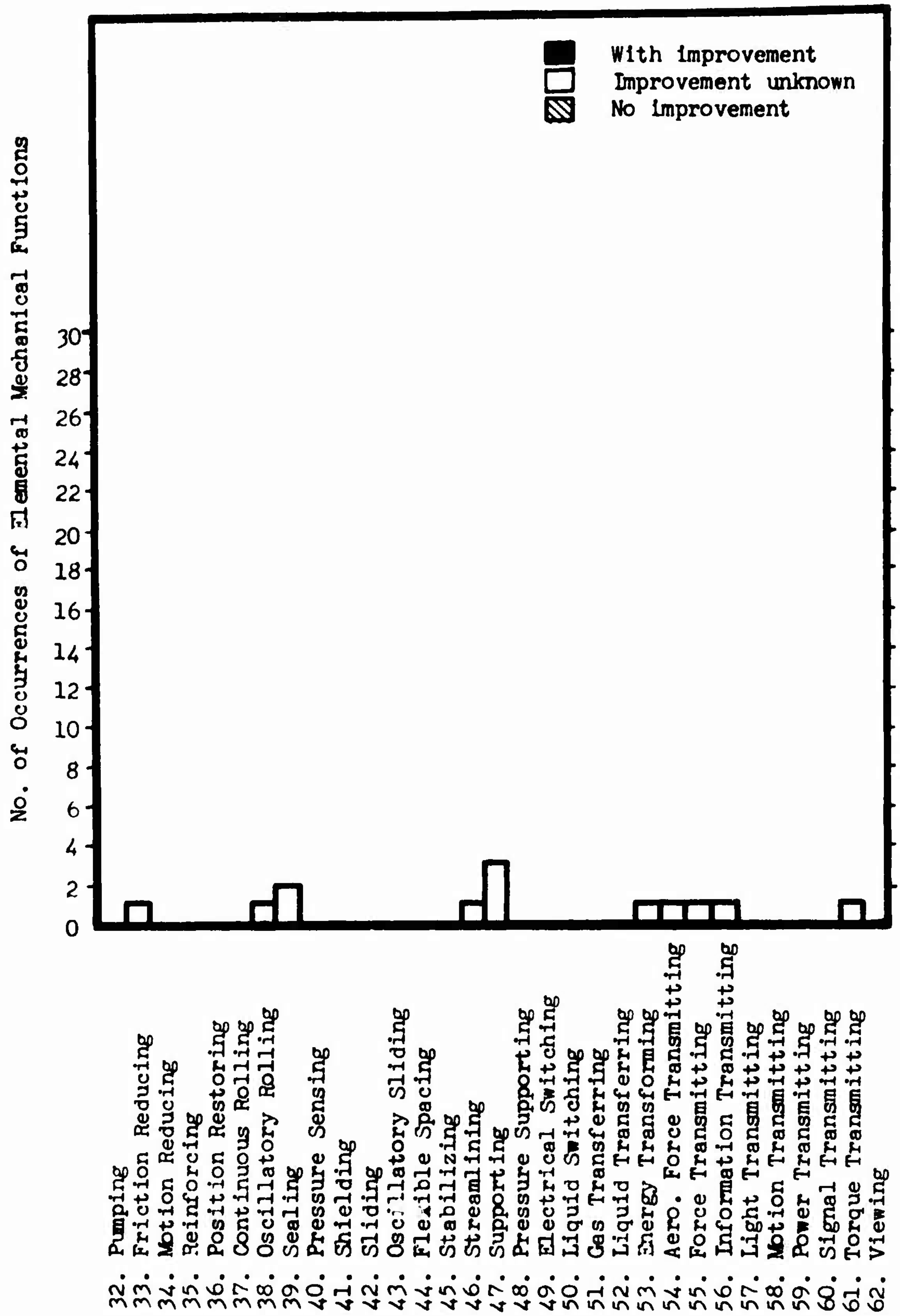


Figure 52 - Continued.

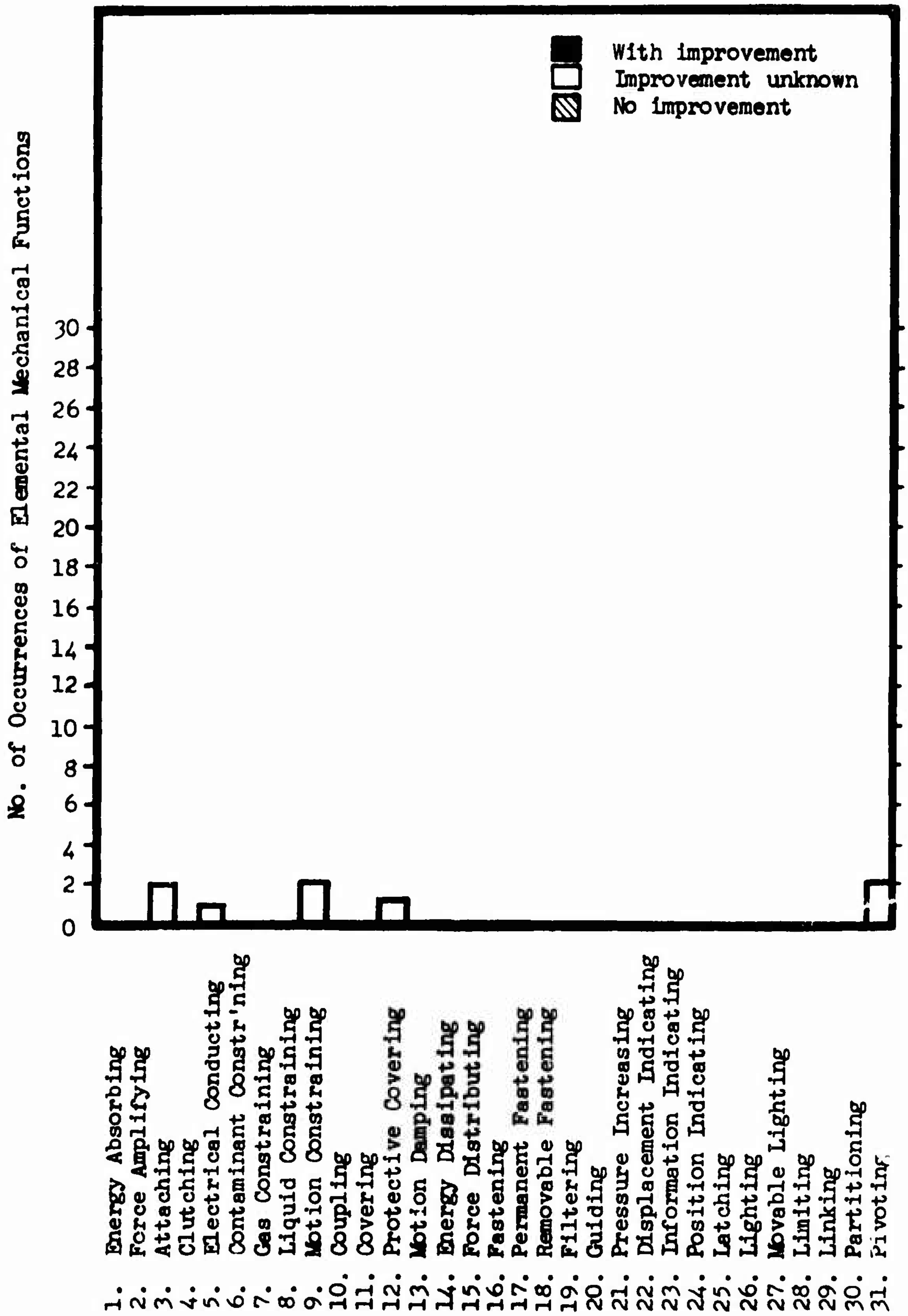


Figure 53. Frequency of Impaired Elemental Functions for the Improved Quality Control Corrective Action - Series II.

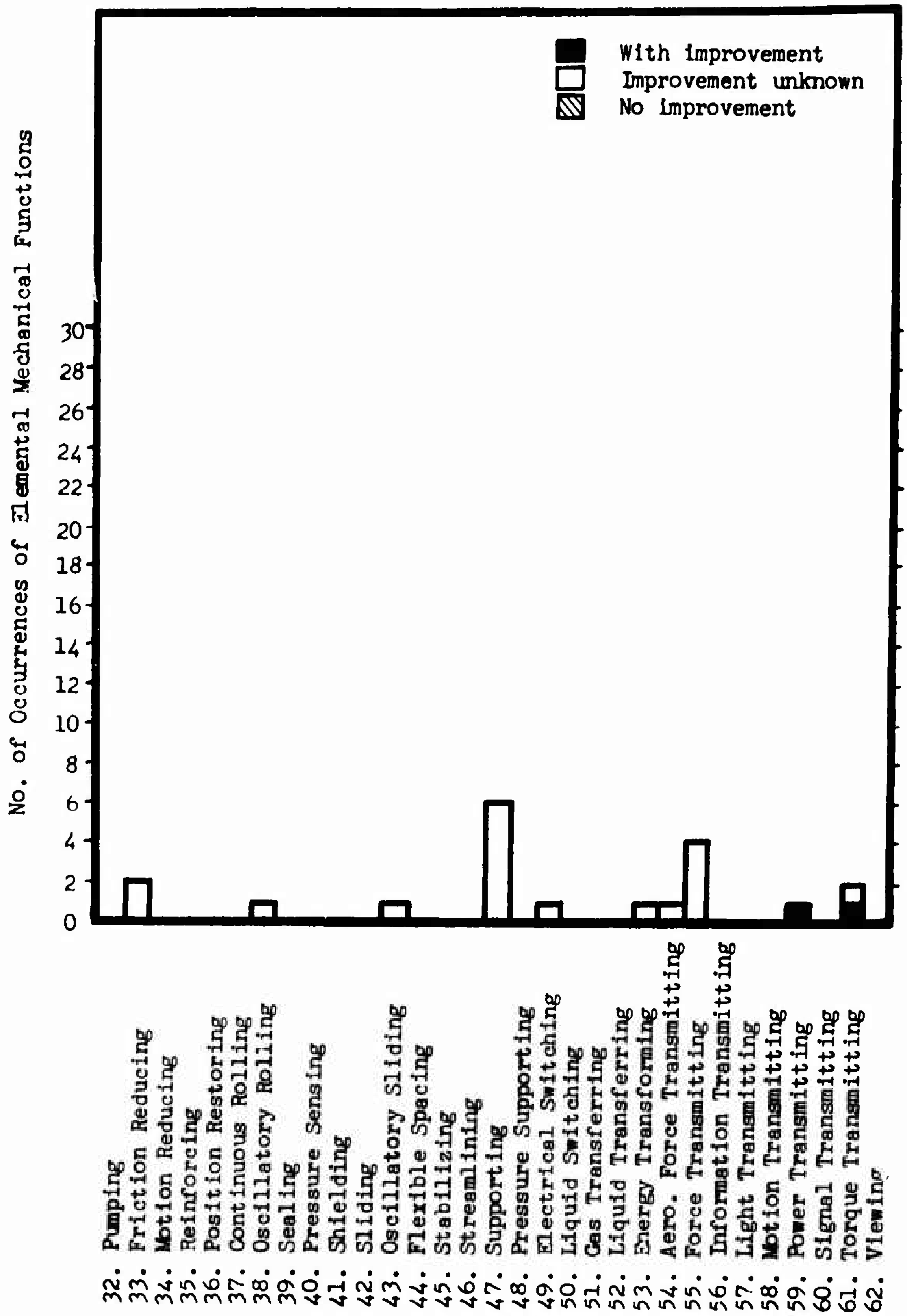


Figure 53 - Continued.

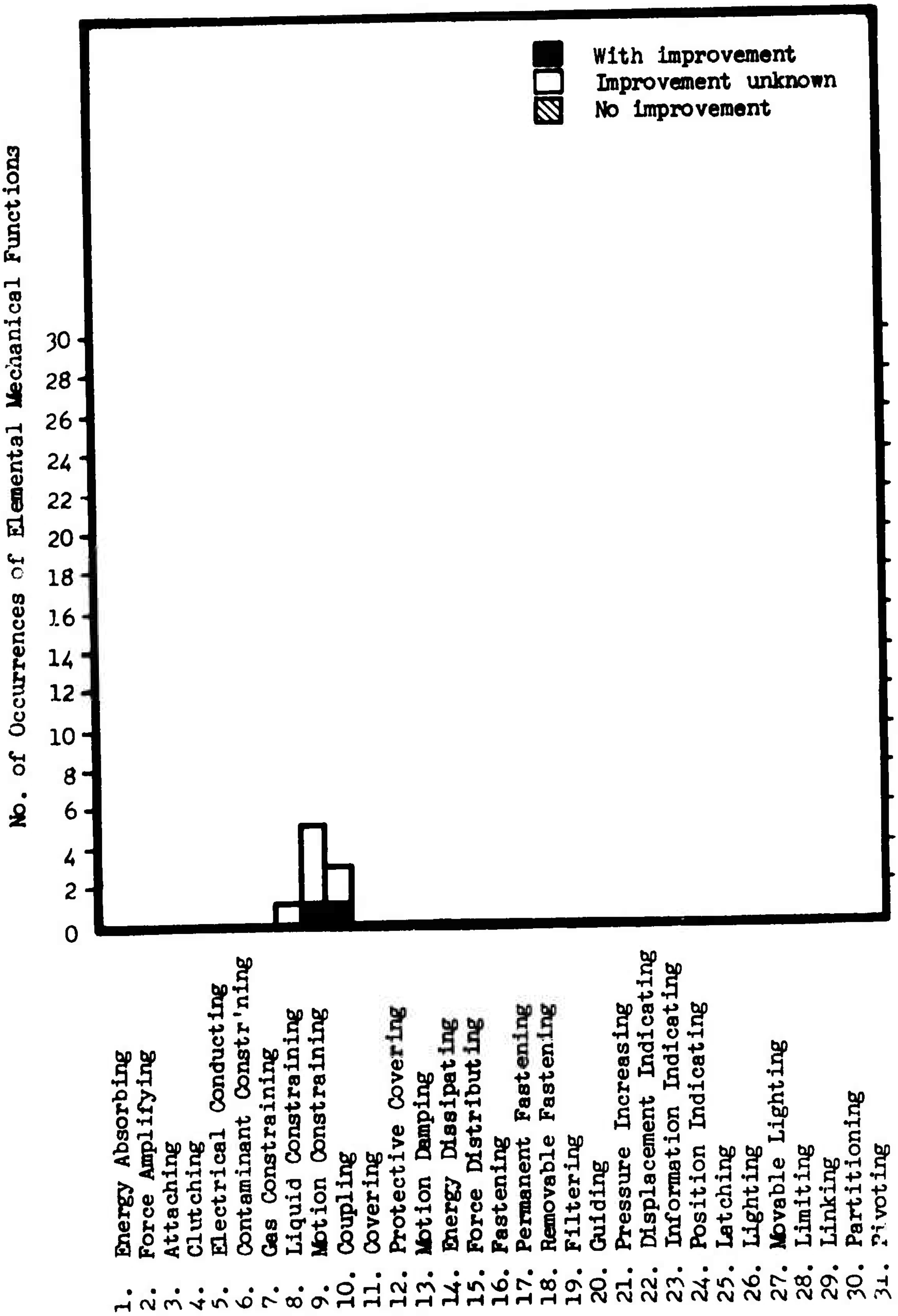


Figure 54. Frequency of Impaired Elemental Functions for the Changed Type or Added Lubricant Corrective Action - Series II.

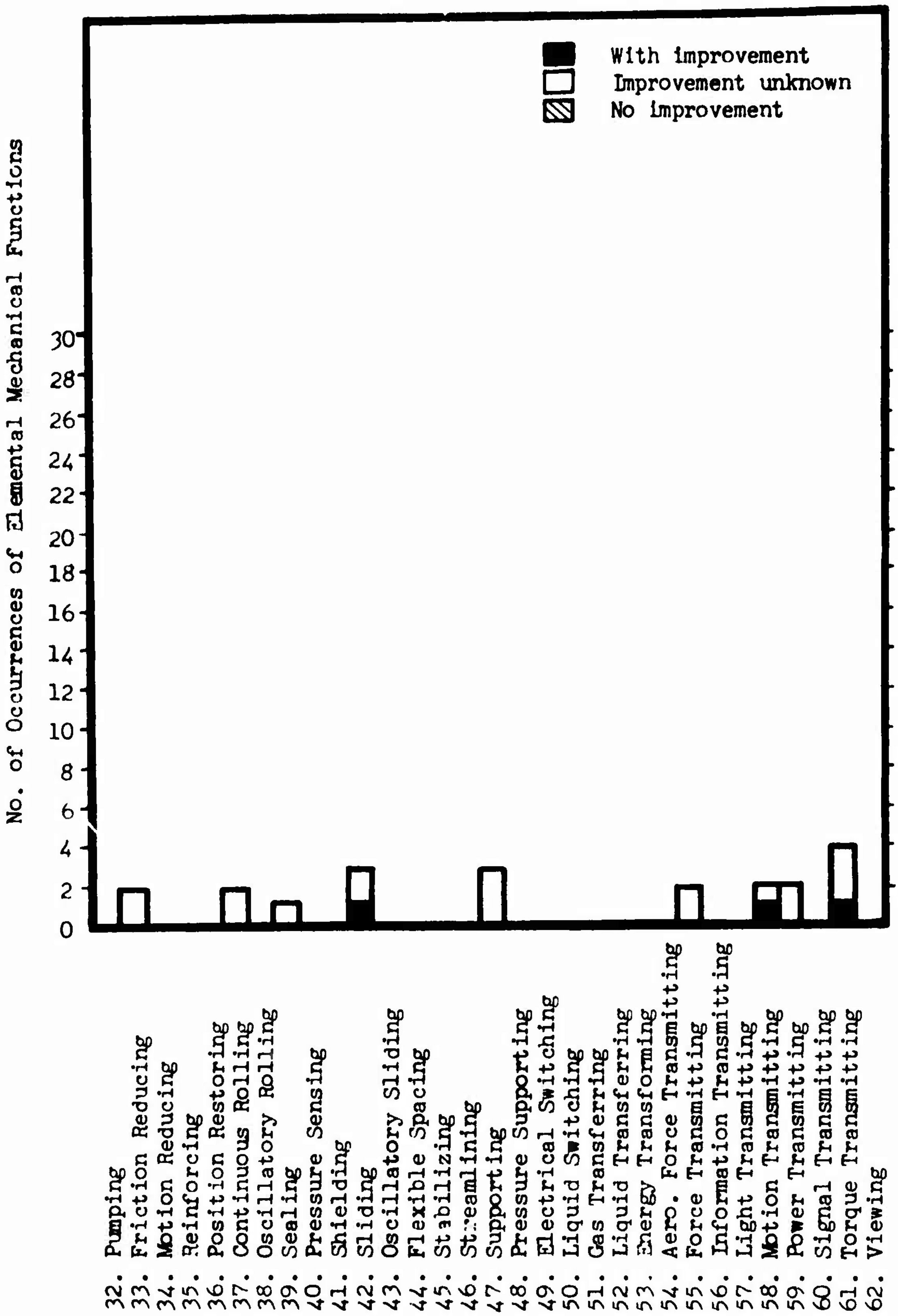


Figure 54 - Continued.

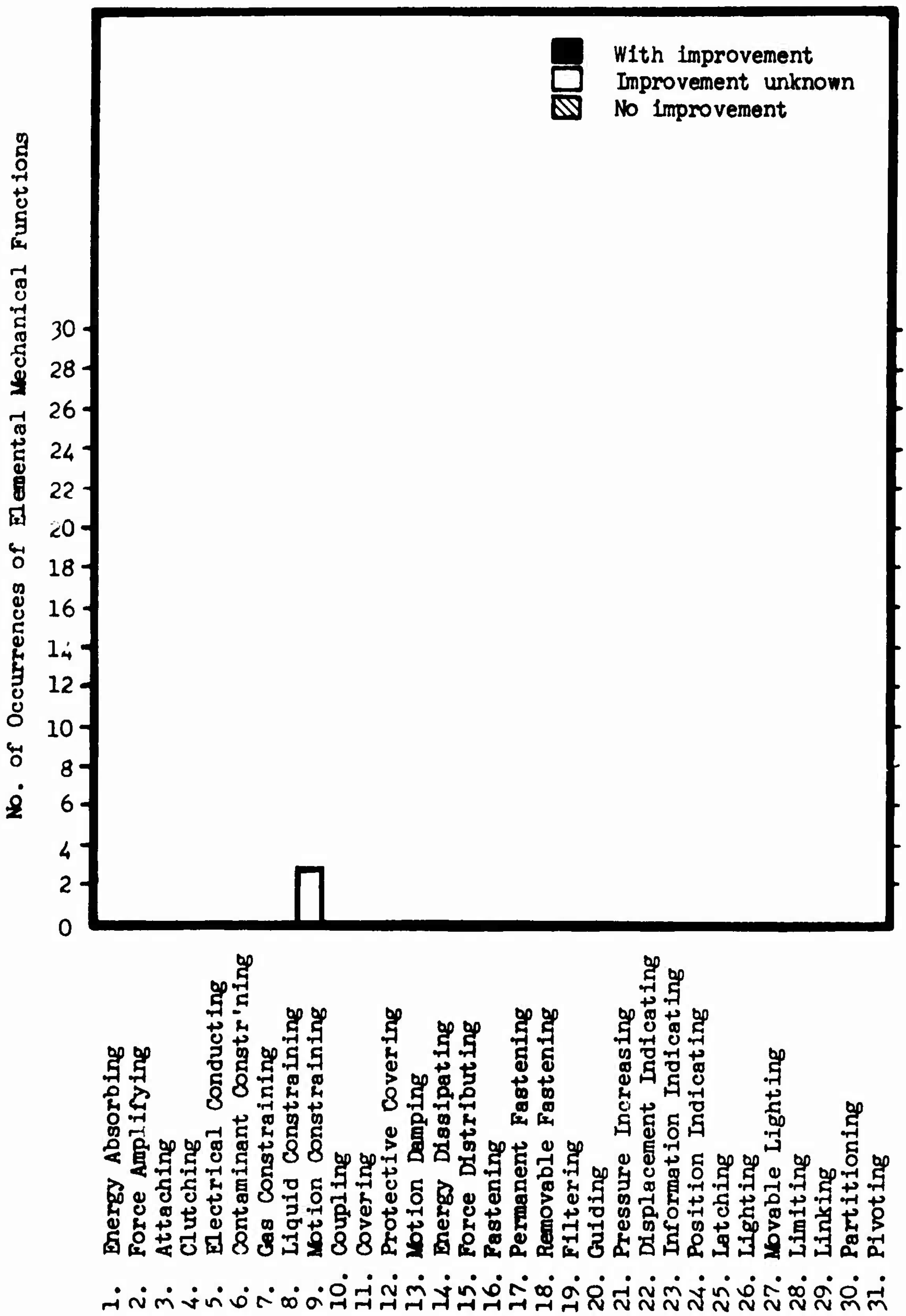


Figure 55. Frequency of Impaired Elemental Functions for the Improved Run-In Procedure Corrective Action - Series II.

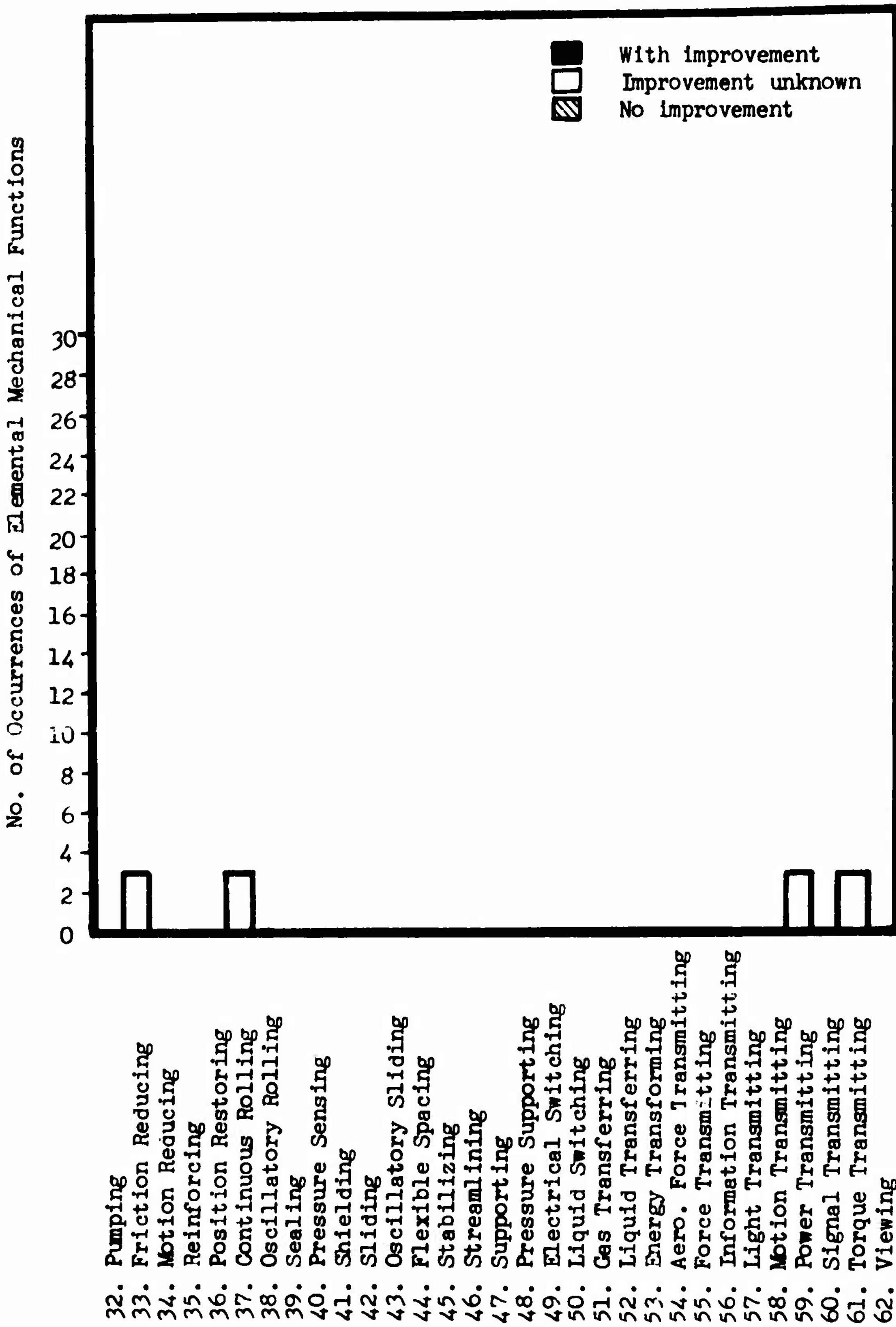


Figure 55 - Continued.

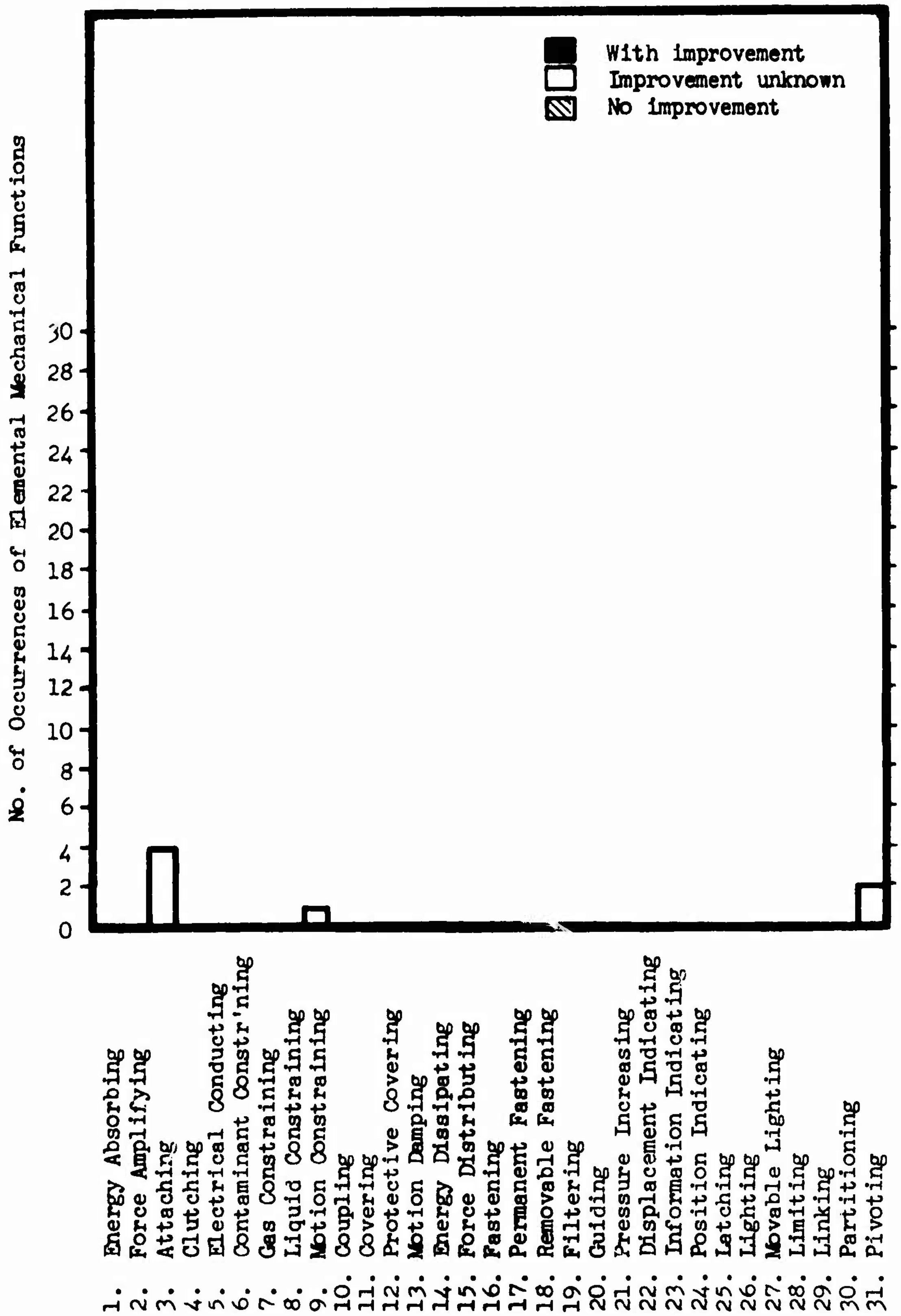


Figure 56. Frequency of Impaired Elemental Functions for the Applied Surface Treatment Corrective Action - Series II.

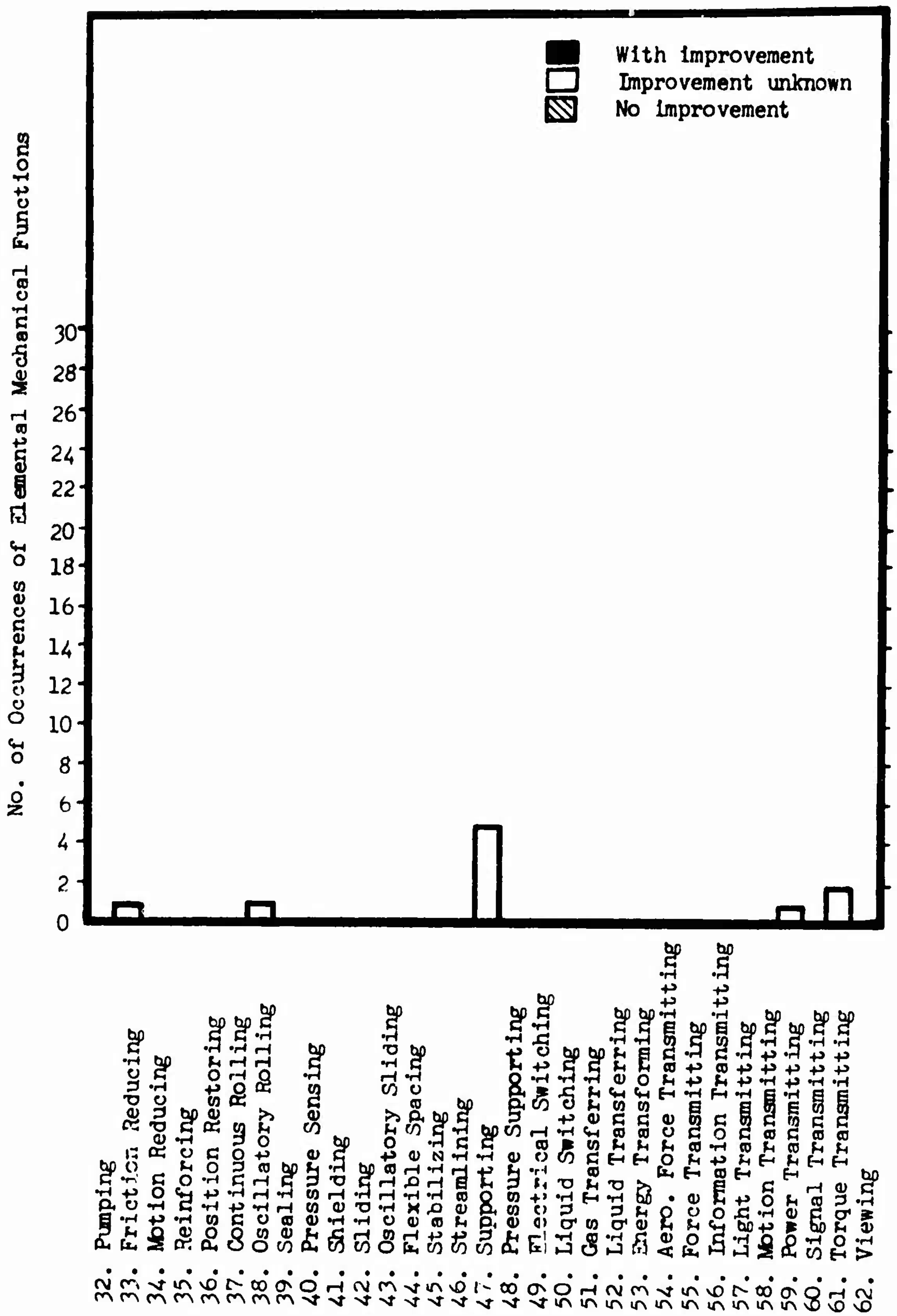


Figure 56 - Continued.

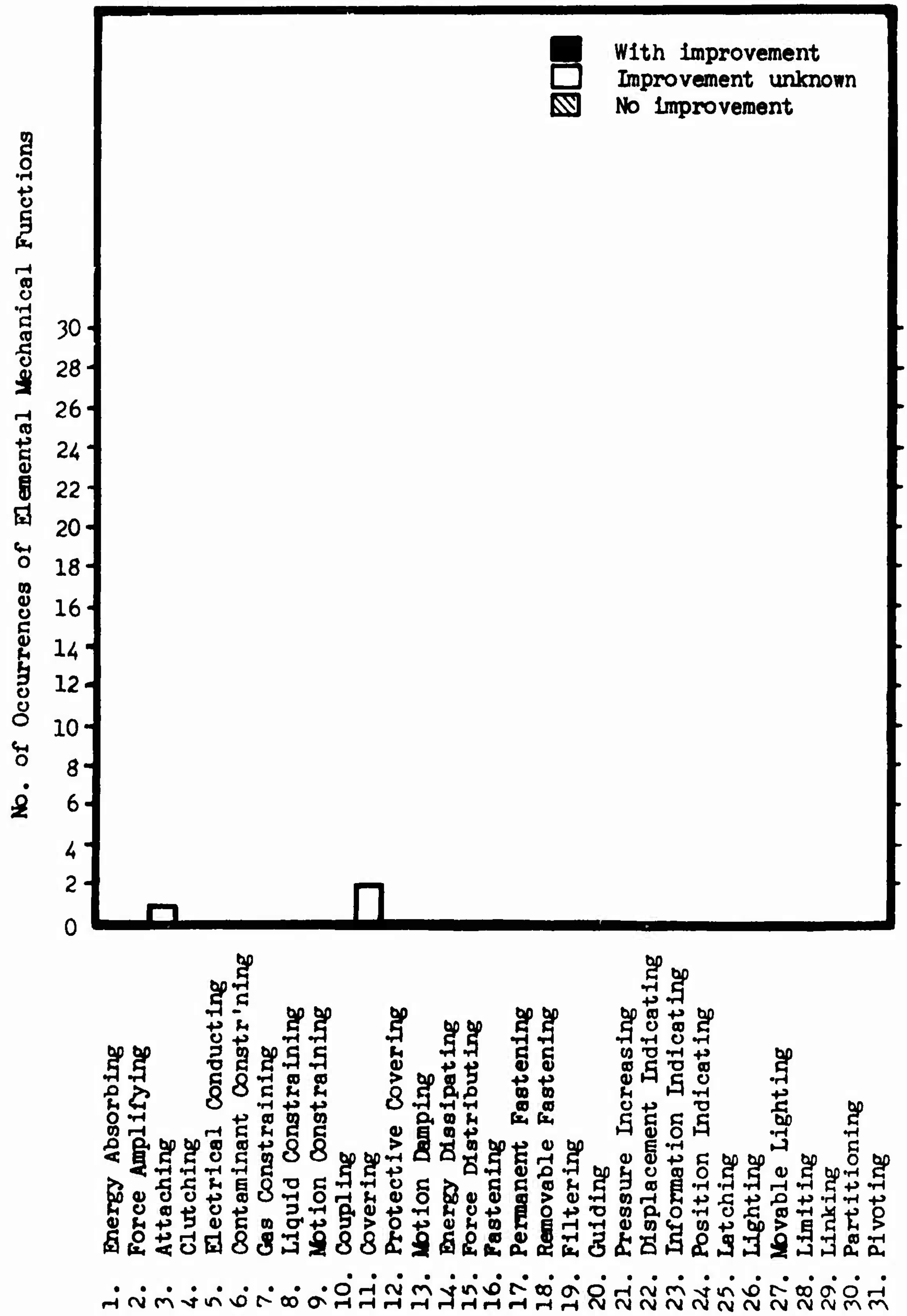


Figure 57. Frequency of Impaired Elemental Functions for the Added Sealant Corrective Action - Series II.

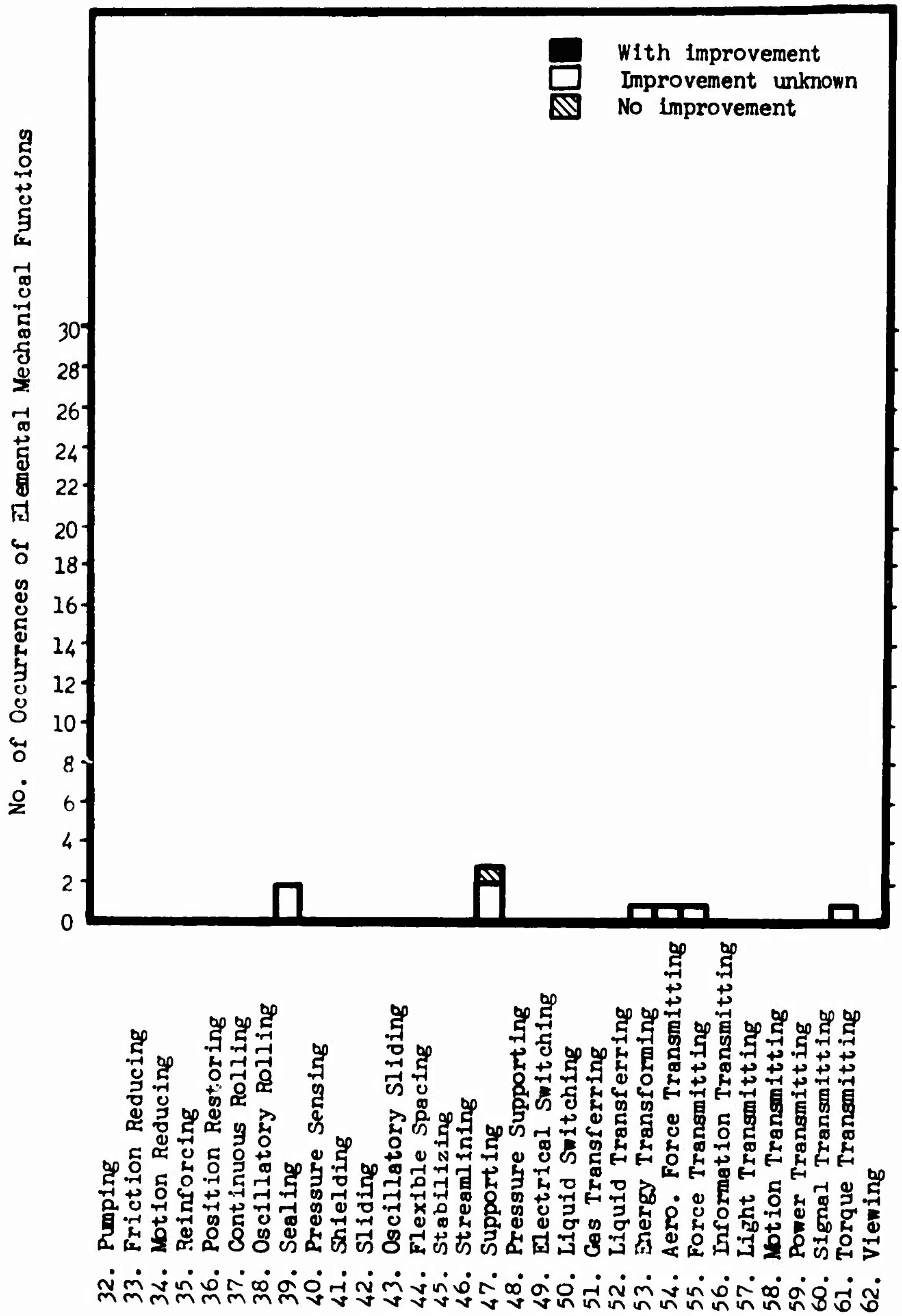


Figure 57 - Continued.

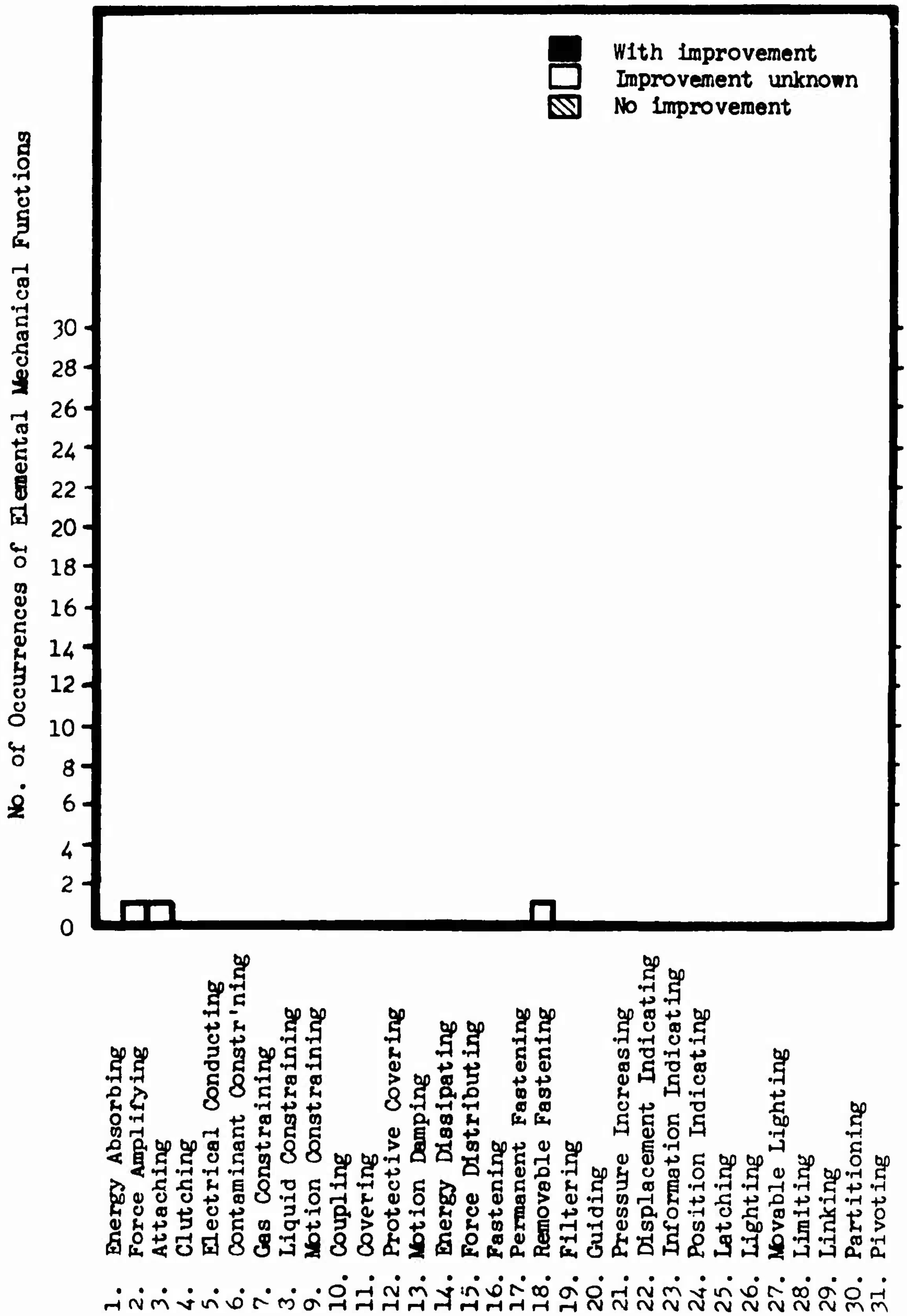
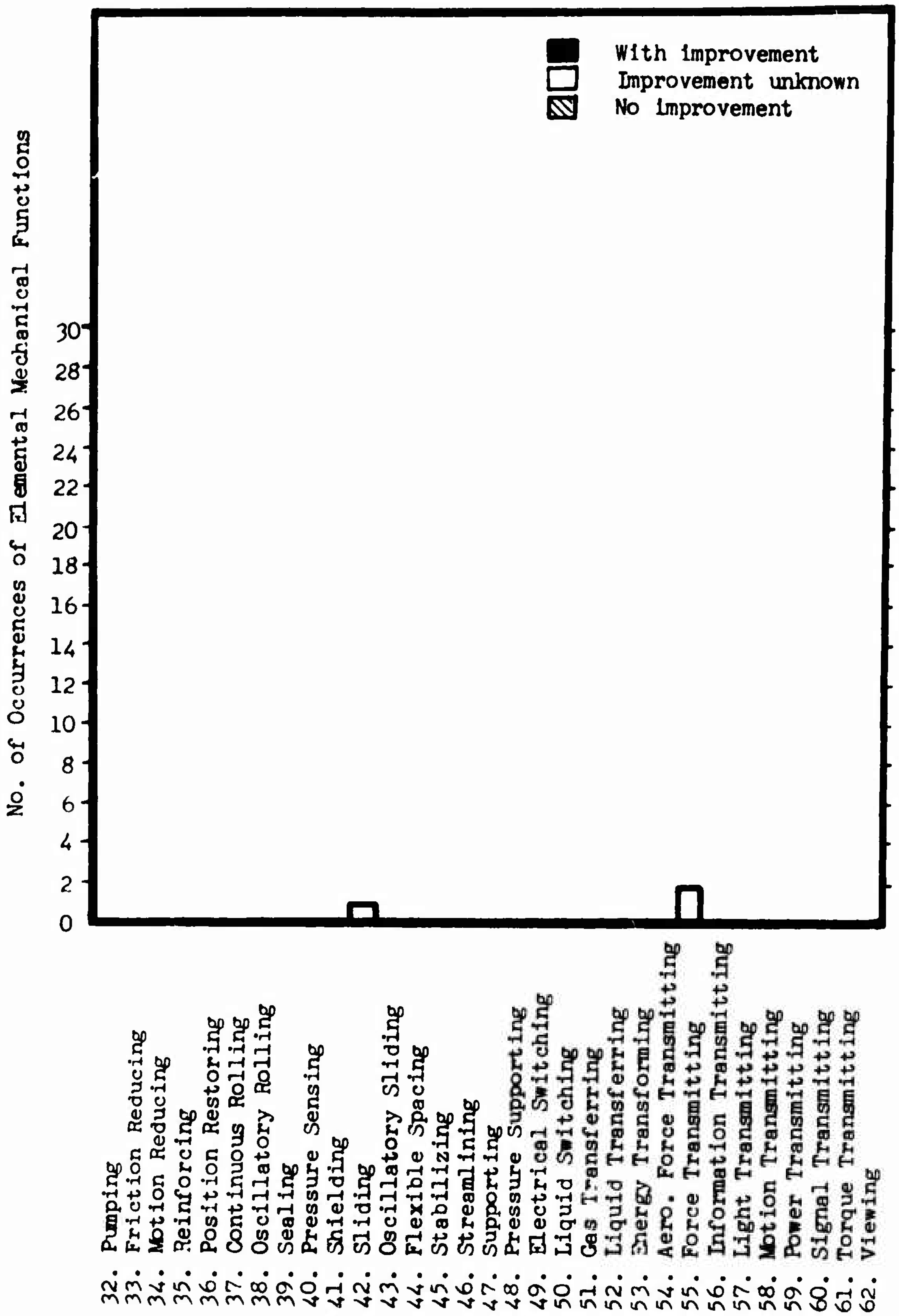


Figure 58. Frequency of Impaired Elemental Functions for the Added or Changed Locking Feature Corrective Action - Series II.



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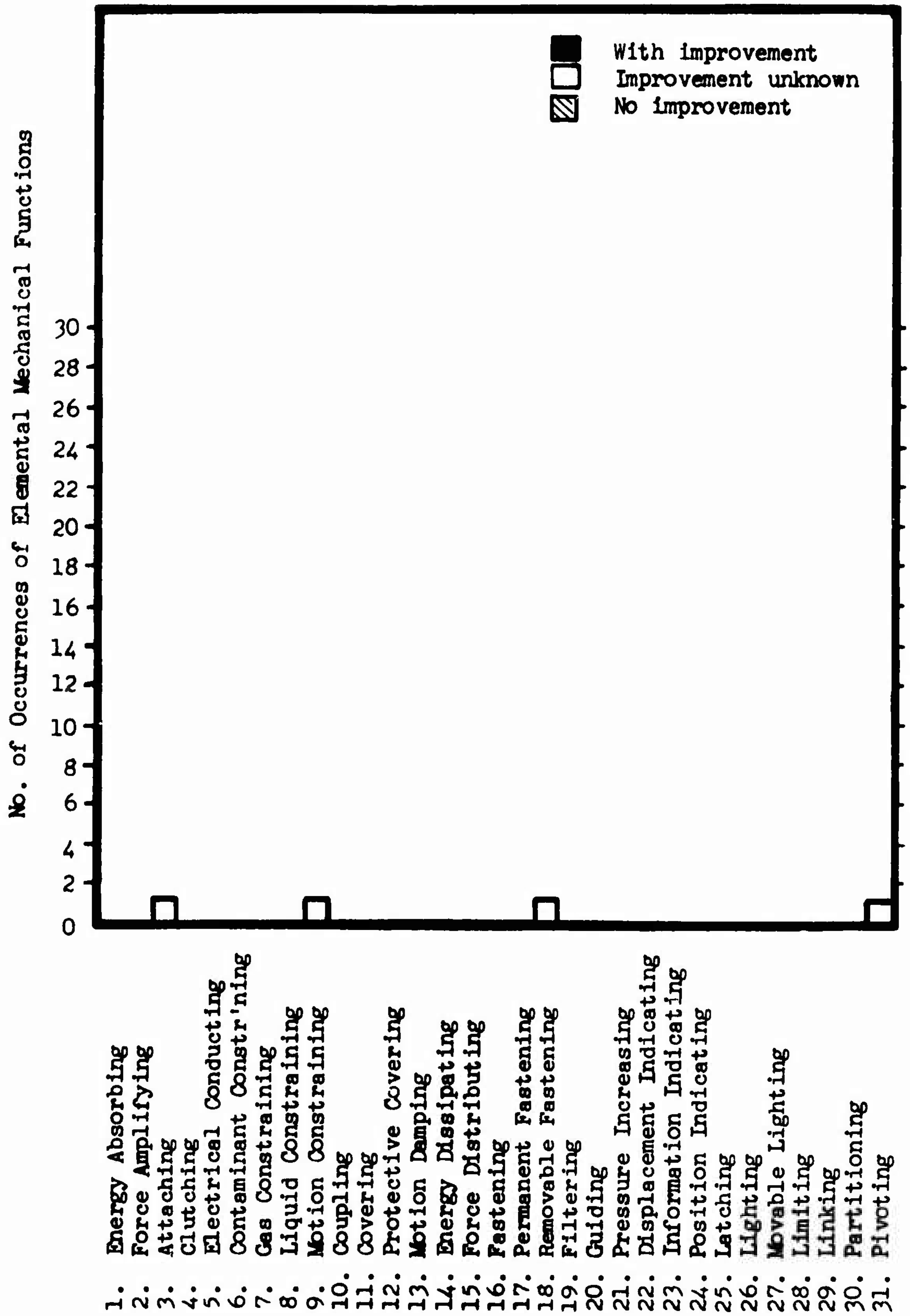
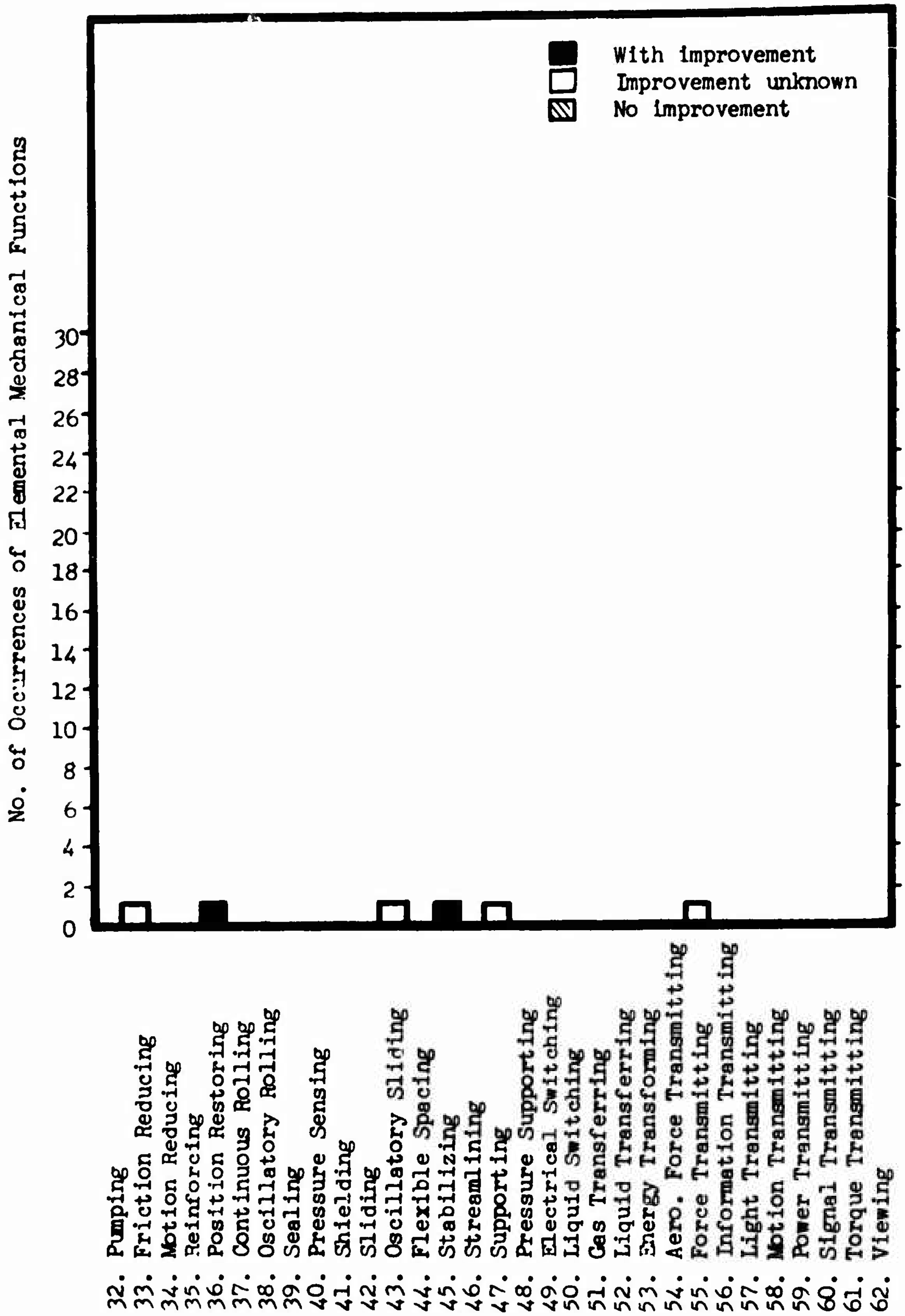


Figure 59. Frequency of Impaired Elemental Functions for the Adjusted Part Corrective Action - Series II.



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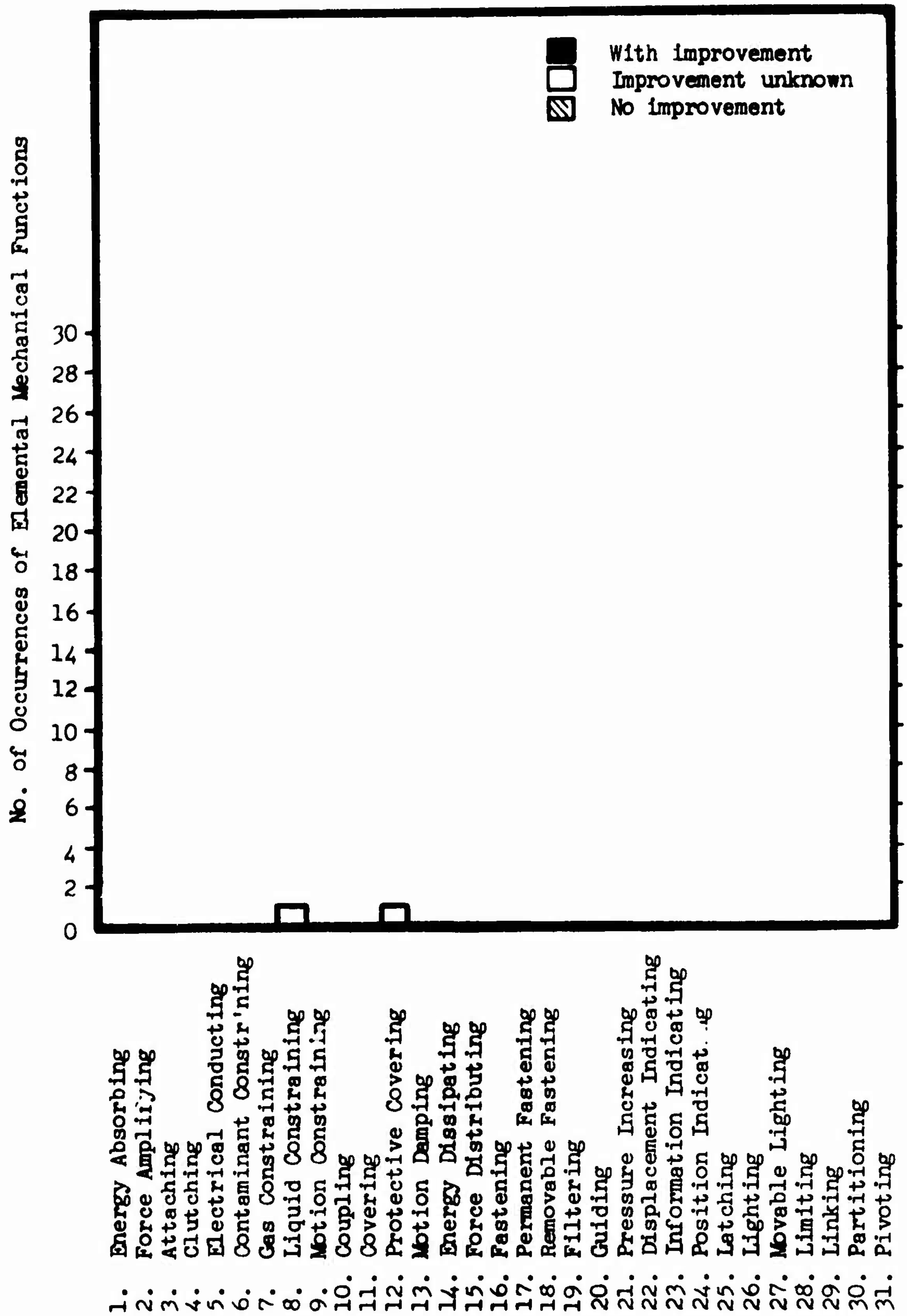
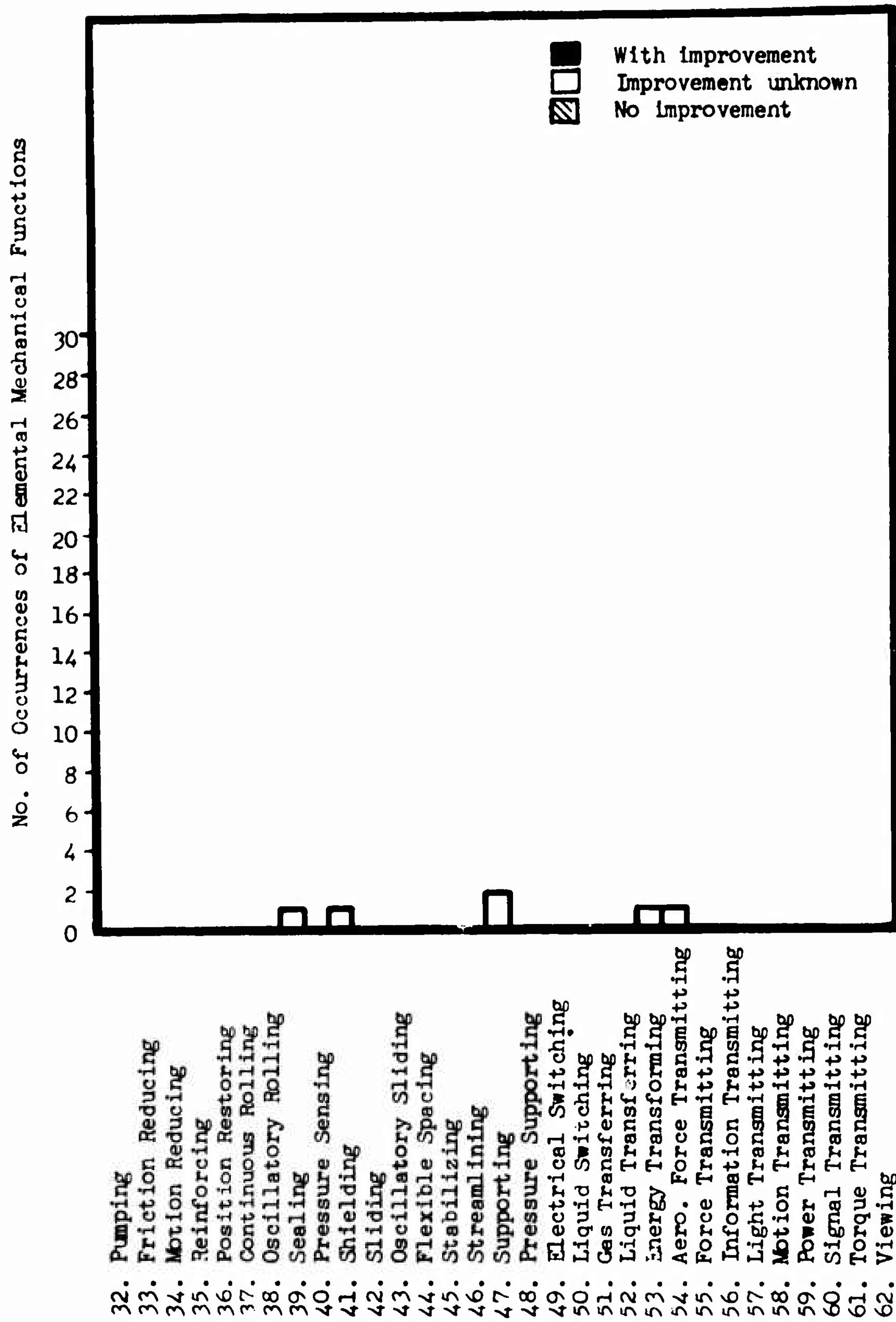


Figure 60. Frequency of Impaired Elemental Functions for the Provided Drain Corrective Action - Series II.



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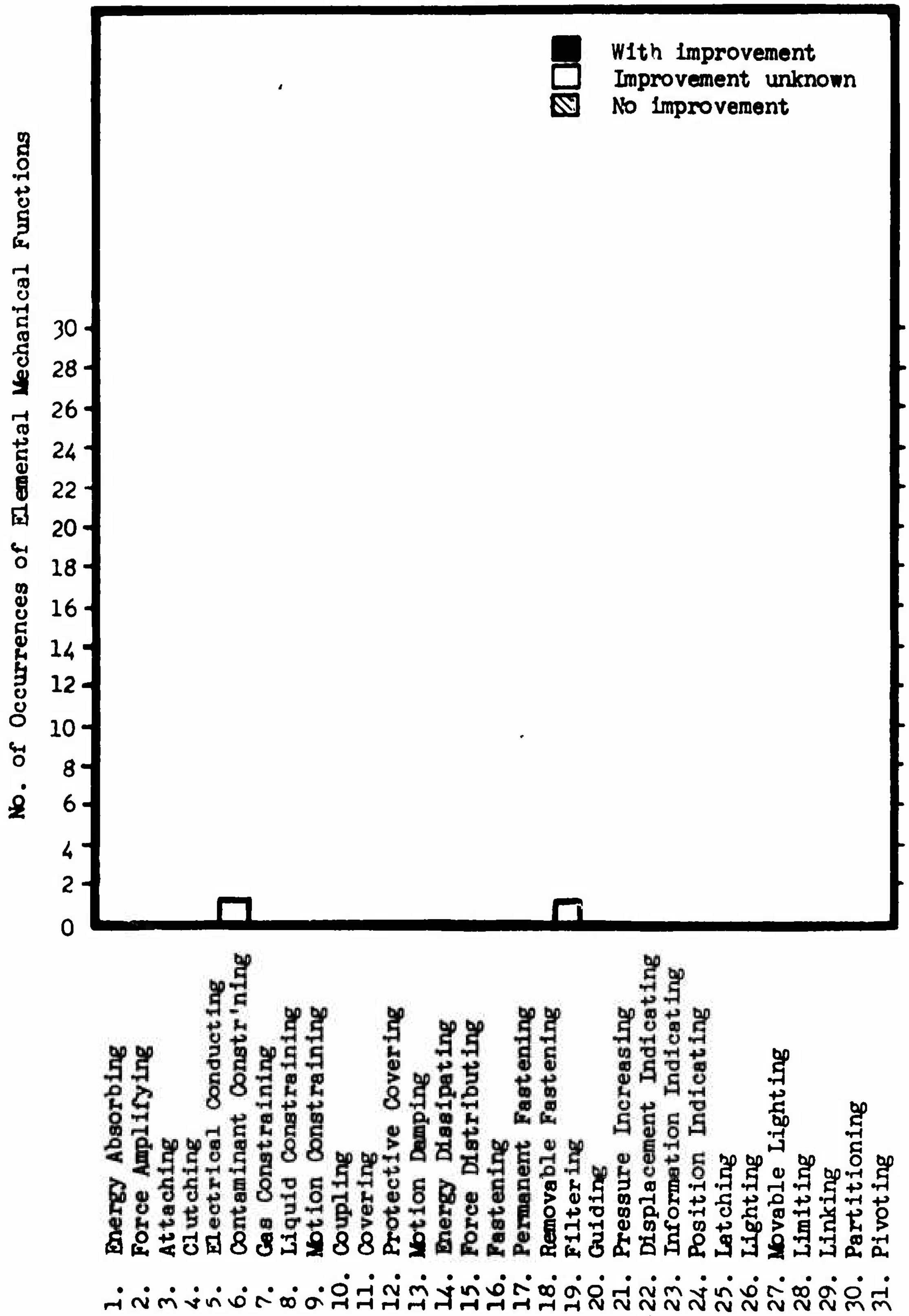
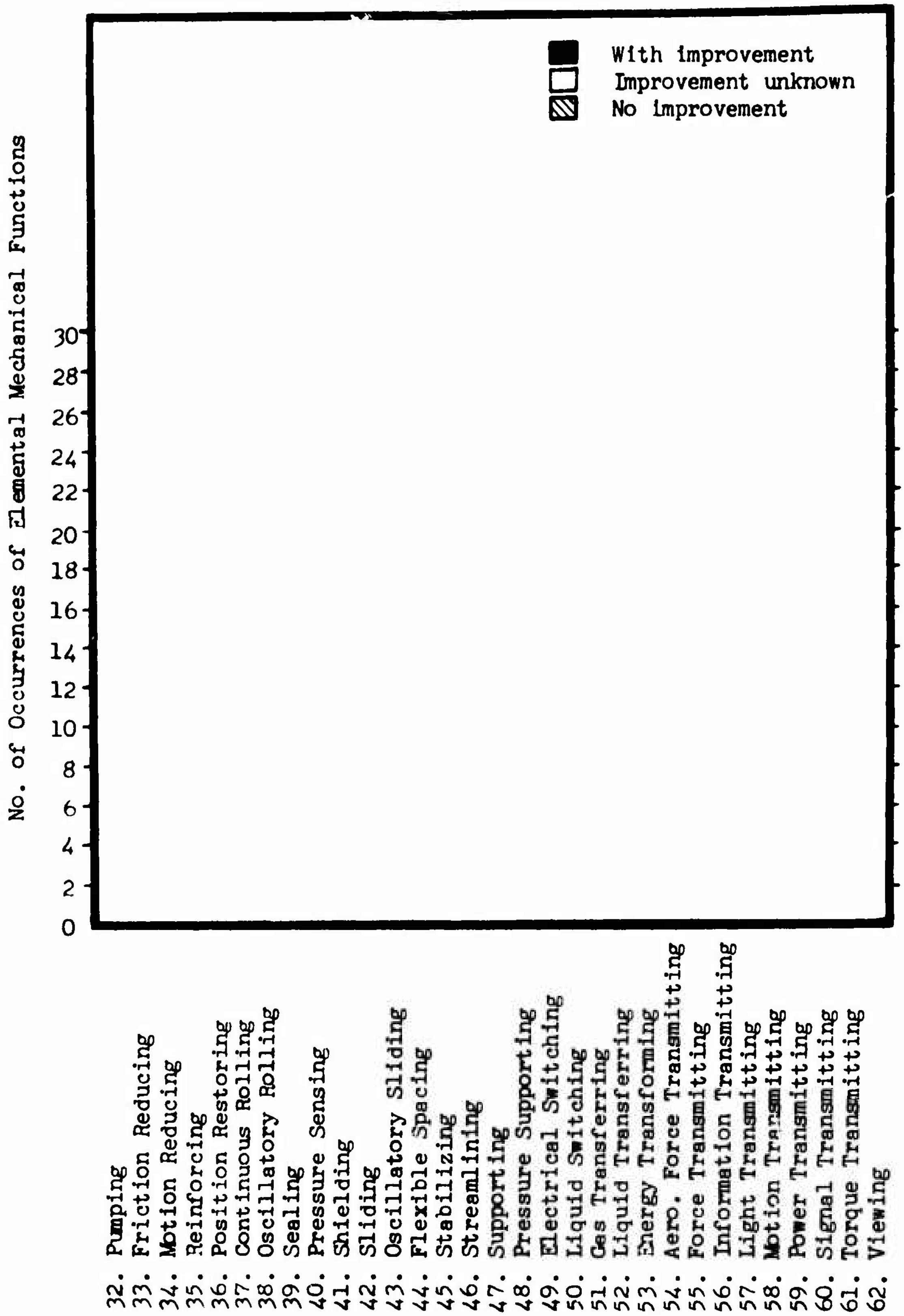


Figure 61. Frequency of Impaired Elemental Functions for the More Easily Replaceable Corrective Action - Series II.



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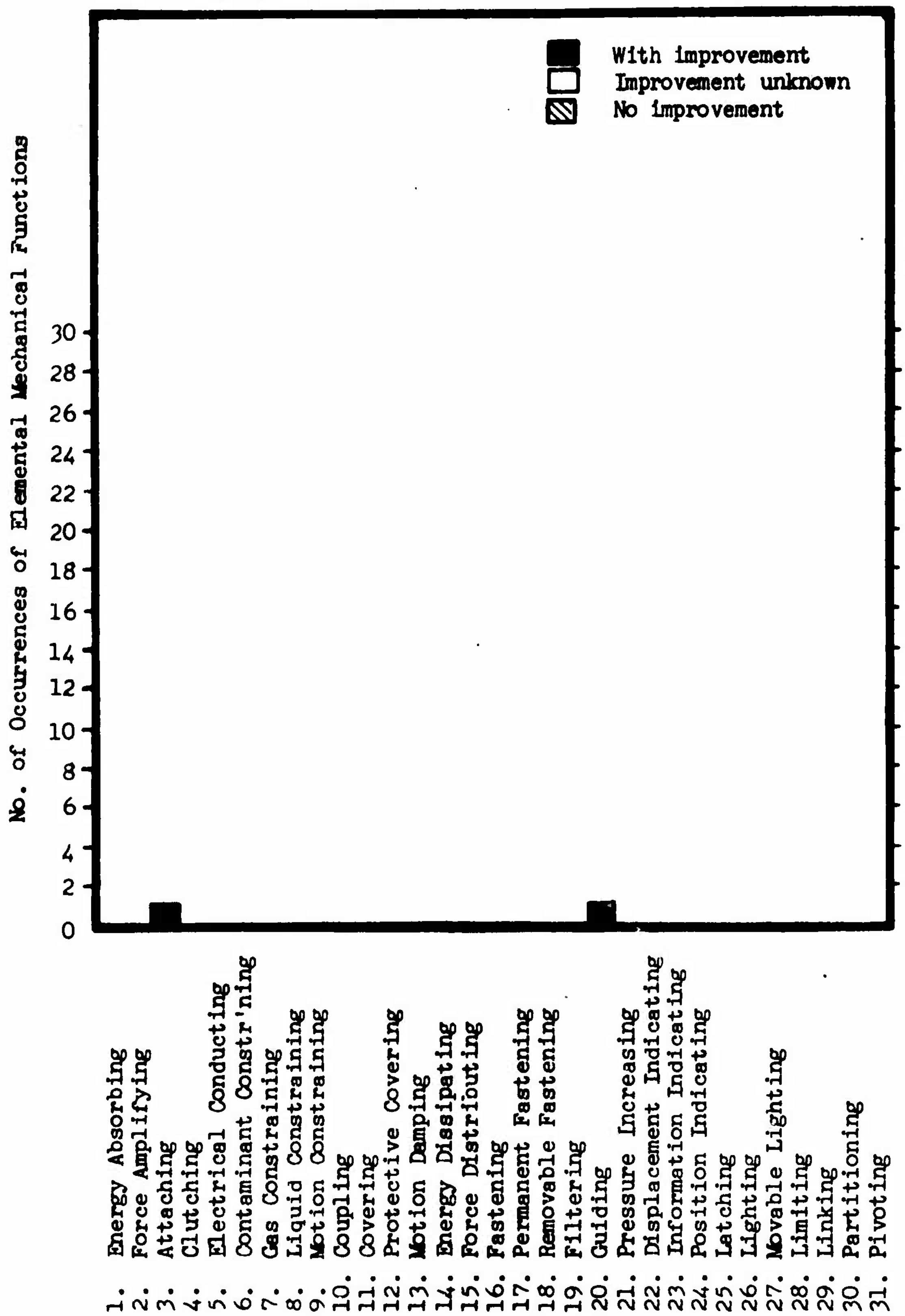
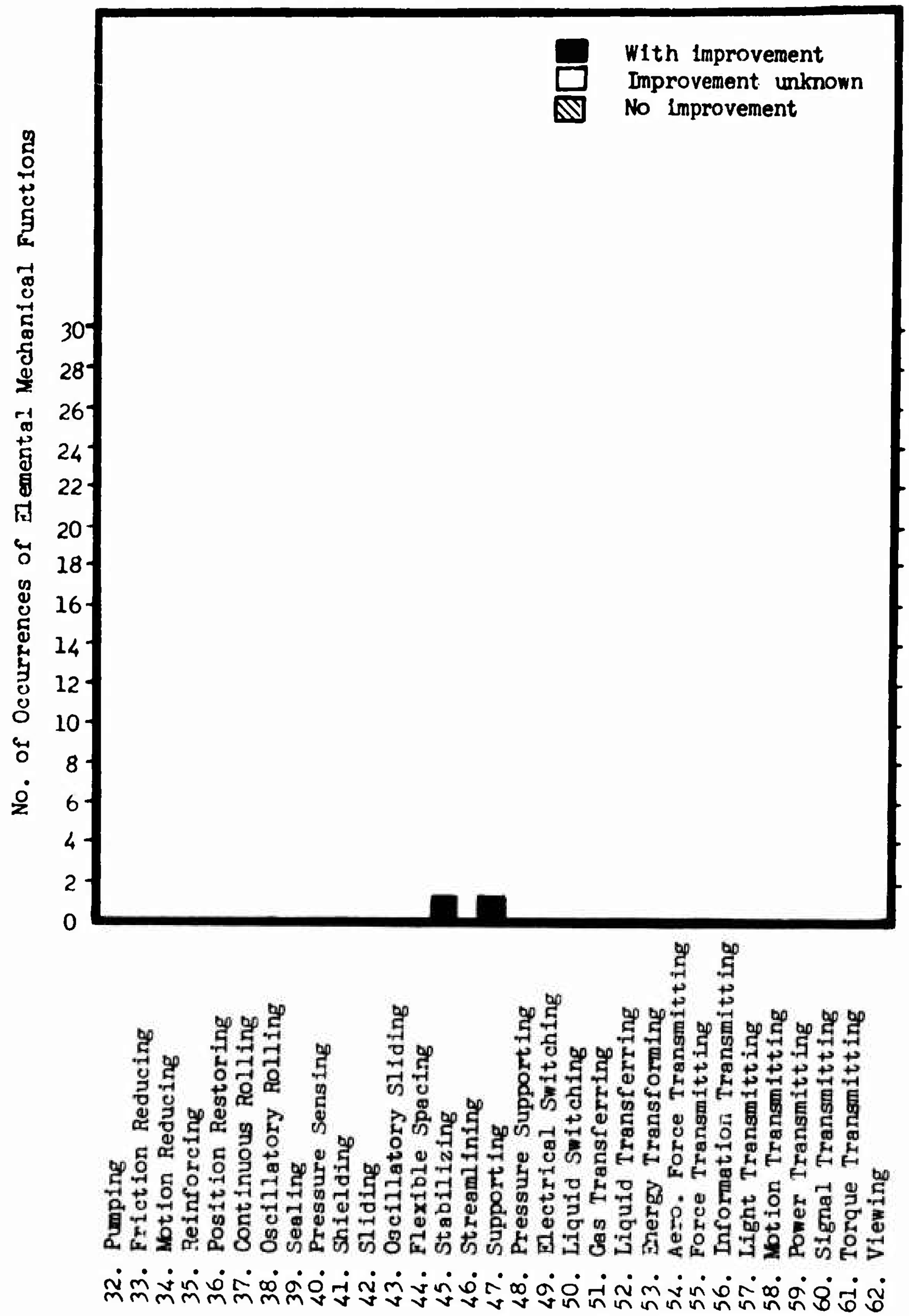


Figure 62. Frequency of Impaired Elemental Functions for the Changed to Correct Part Corrective Action - Series II.



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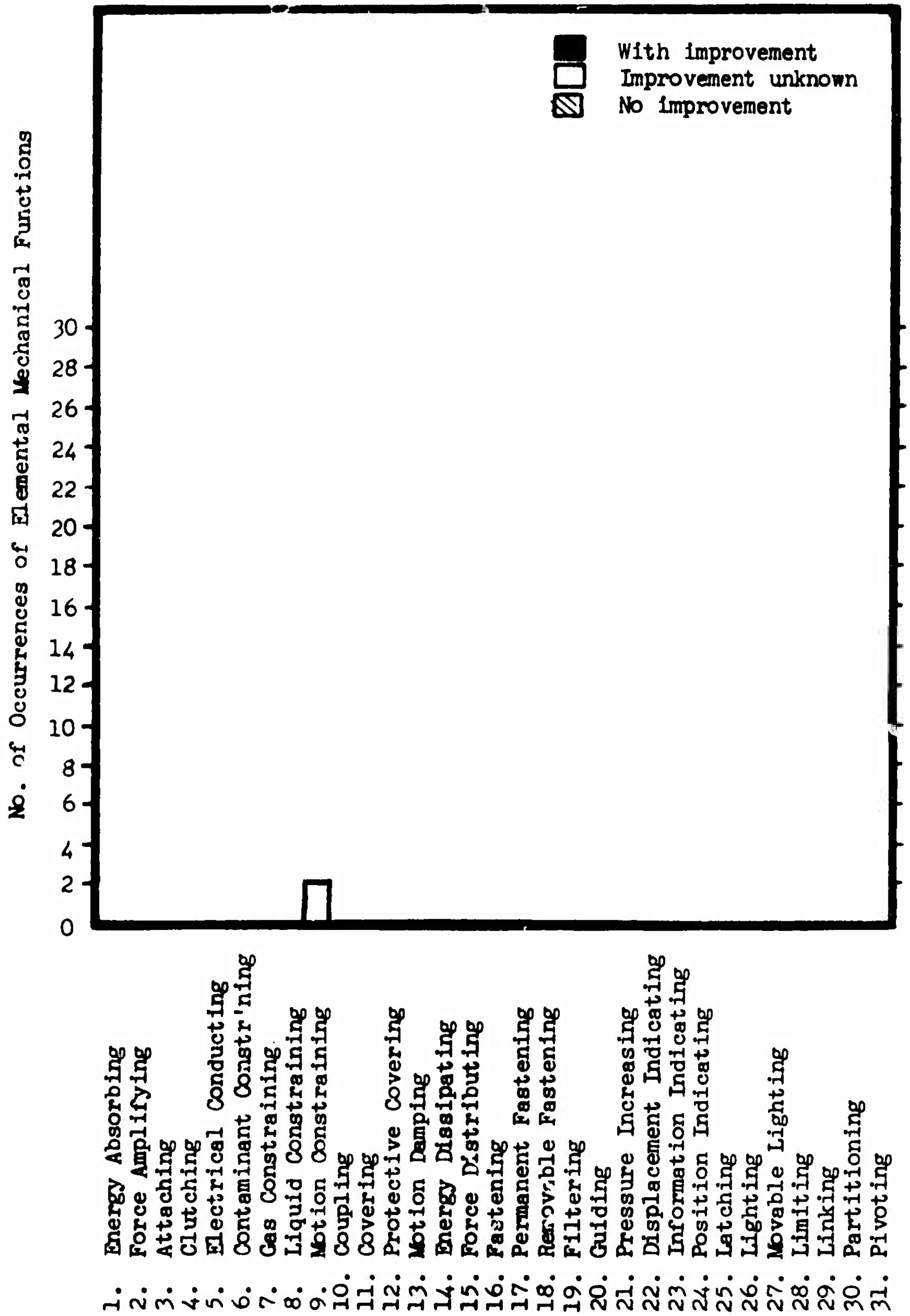
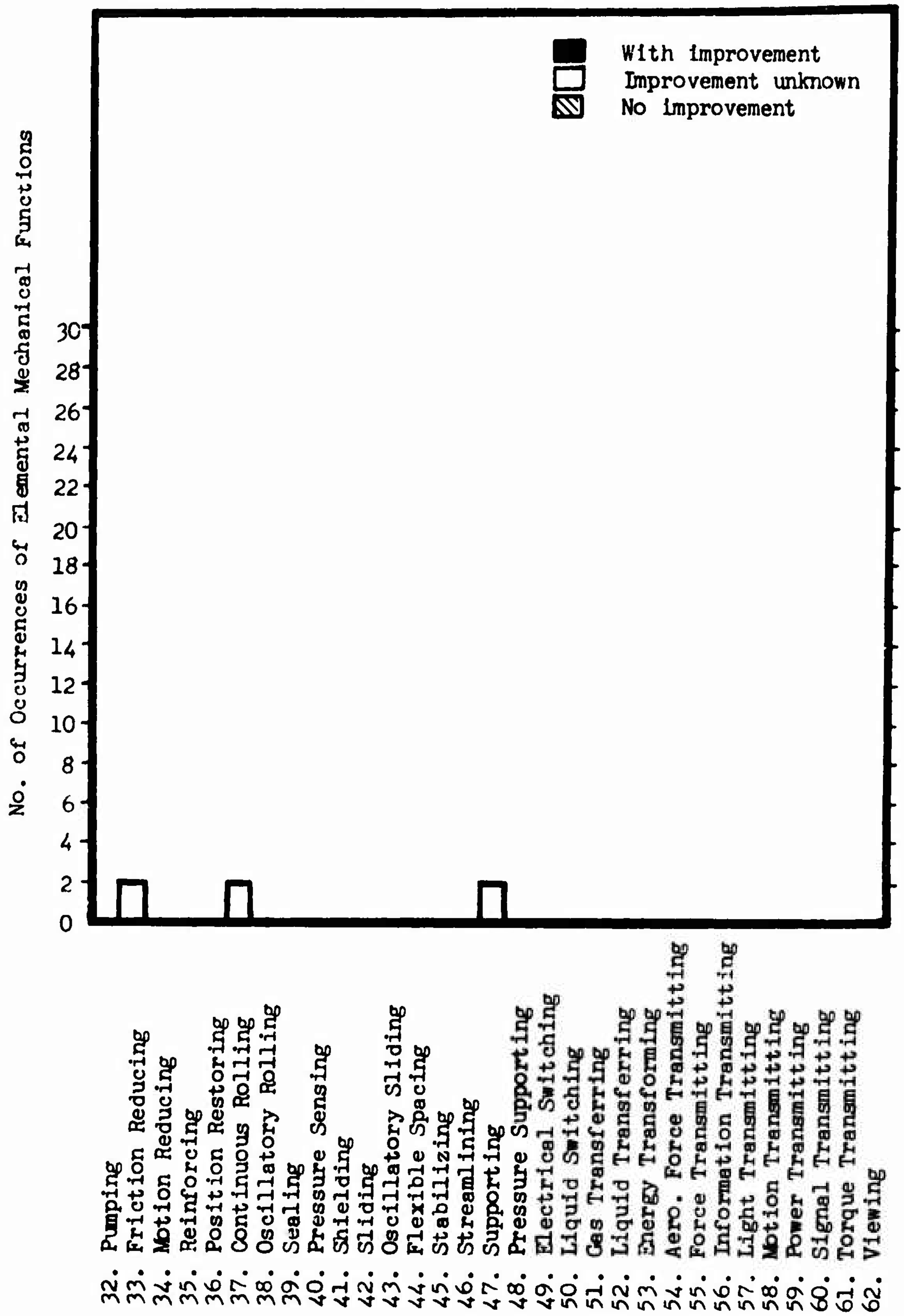


Figure 63. Frequency of Impaired Elemental Functions for the Improved Lubrication Corrective Action - Series II.



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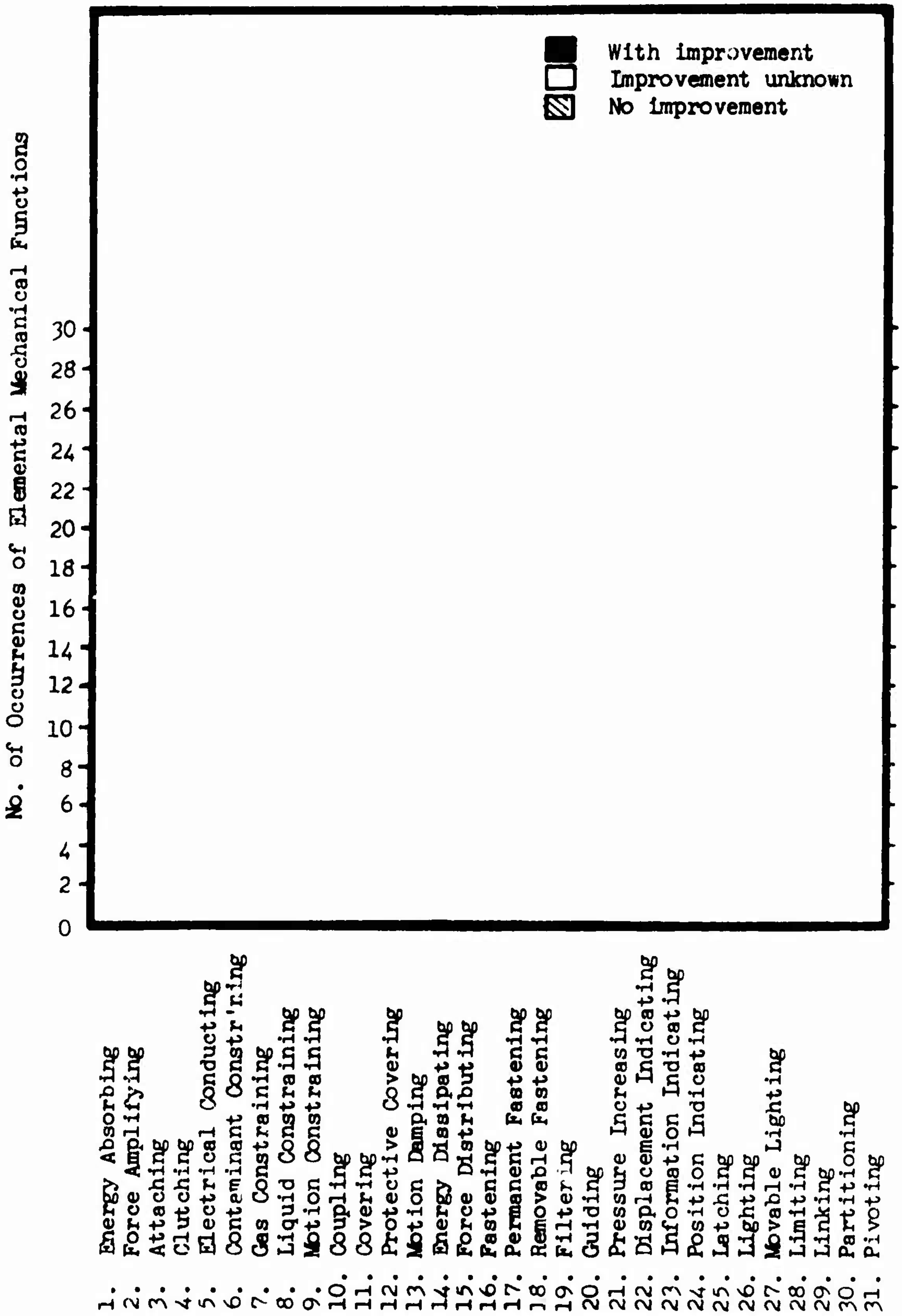
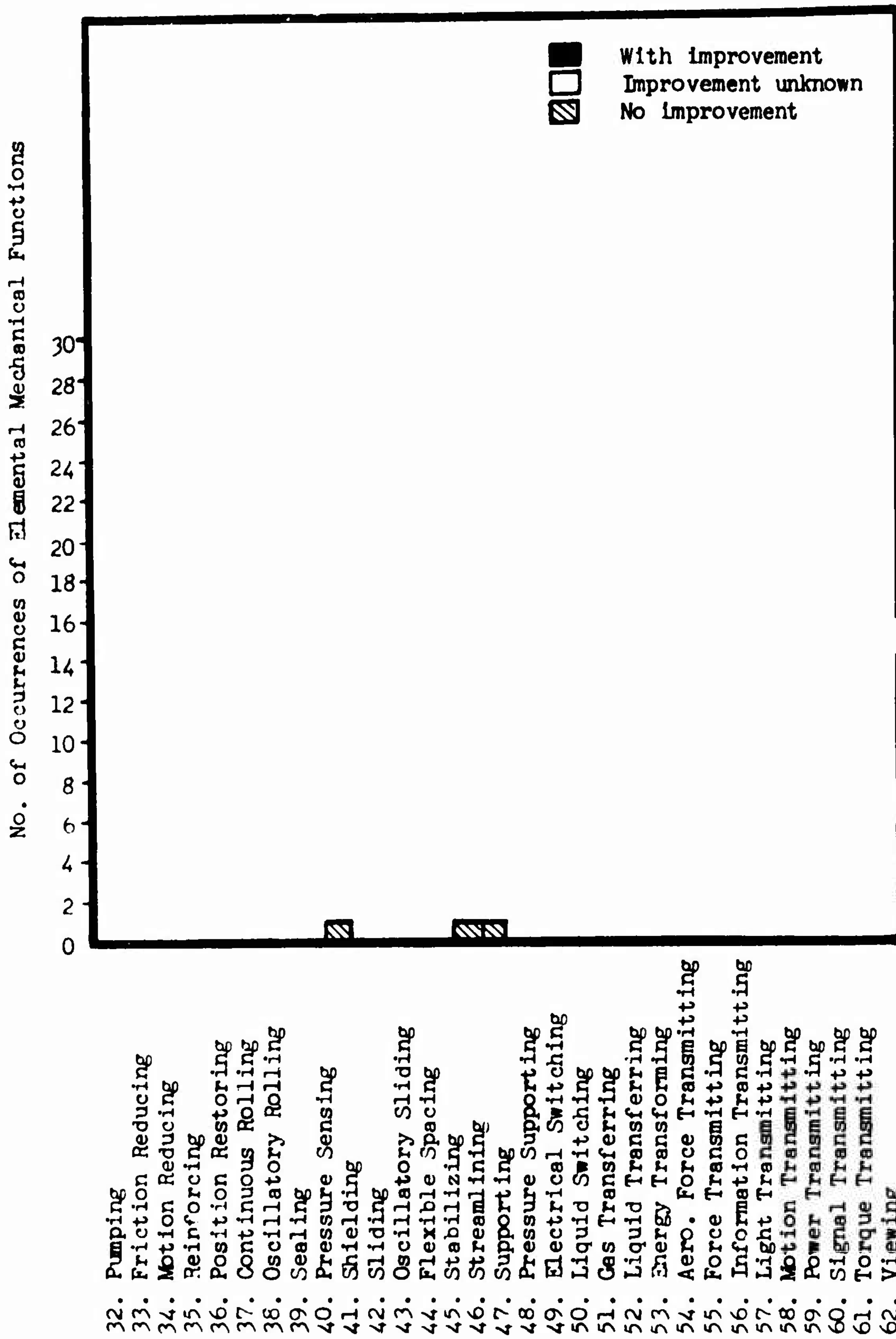


Figure 64. Frequency of Impaired Elemental Functions for the Made Parts Interchangeable Corrective Action - Series II.



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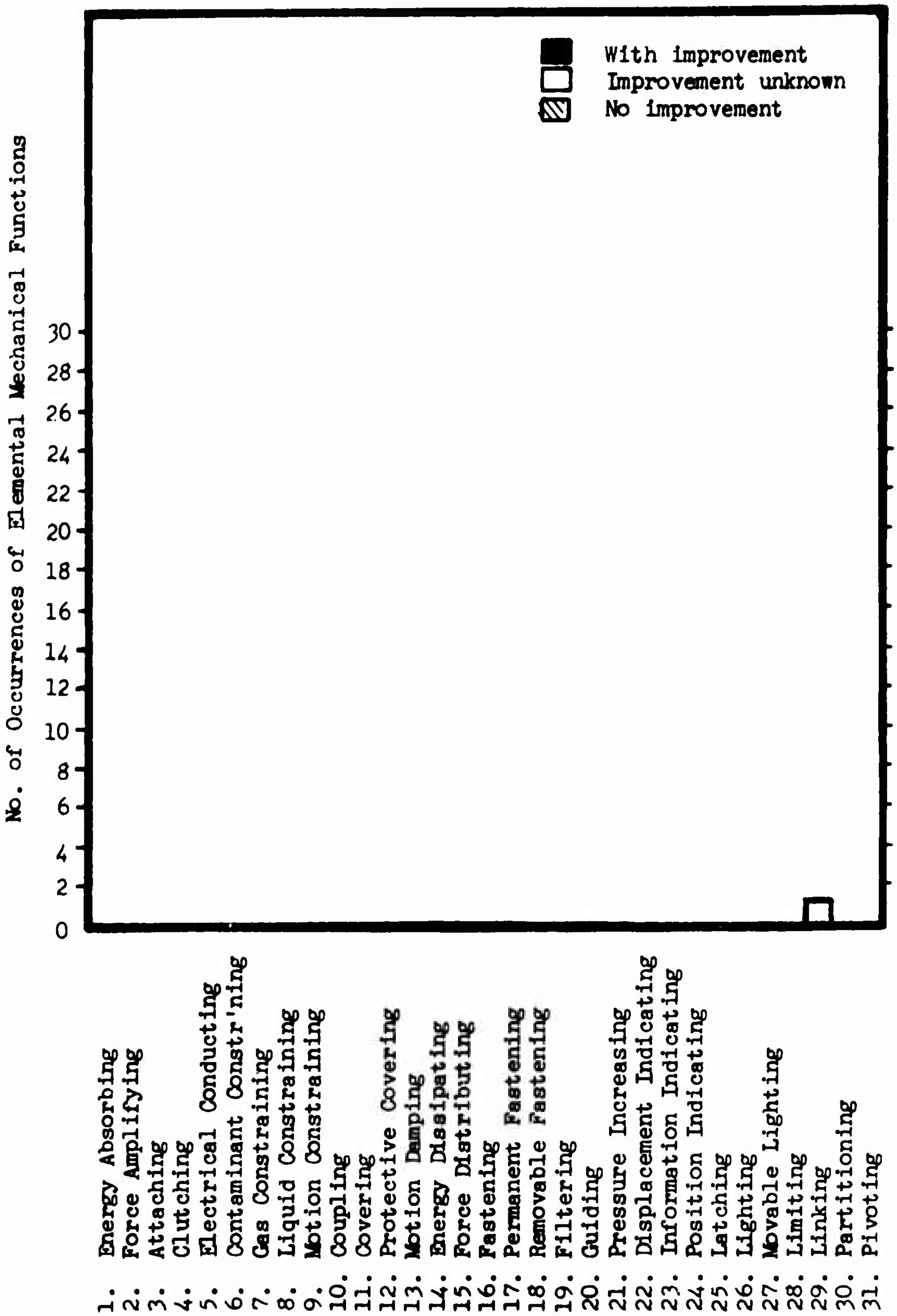
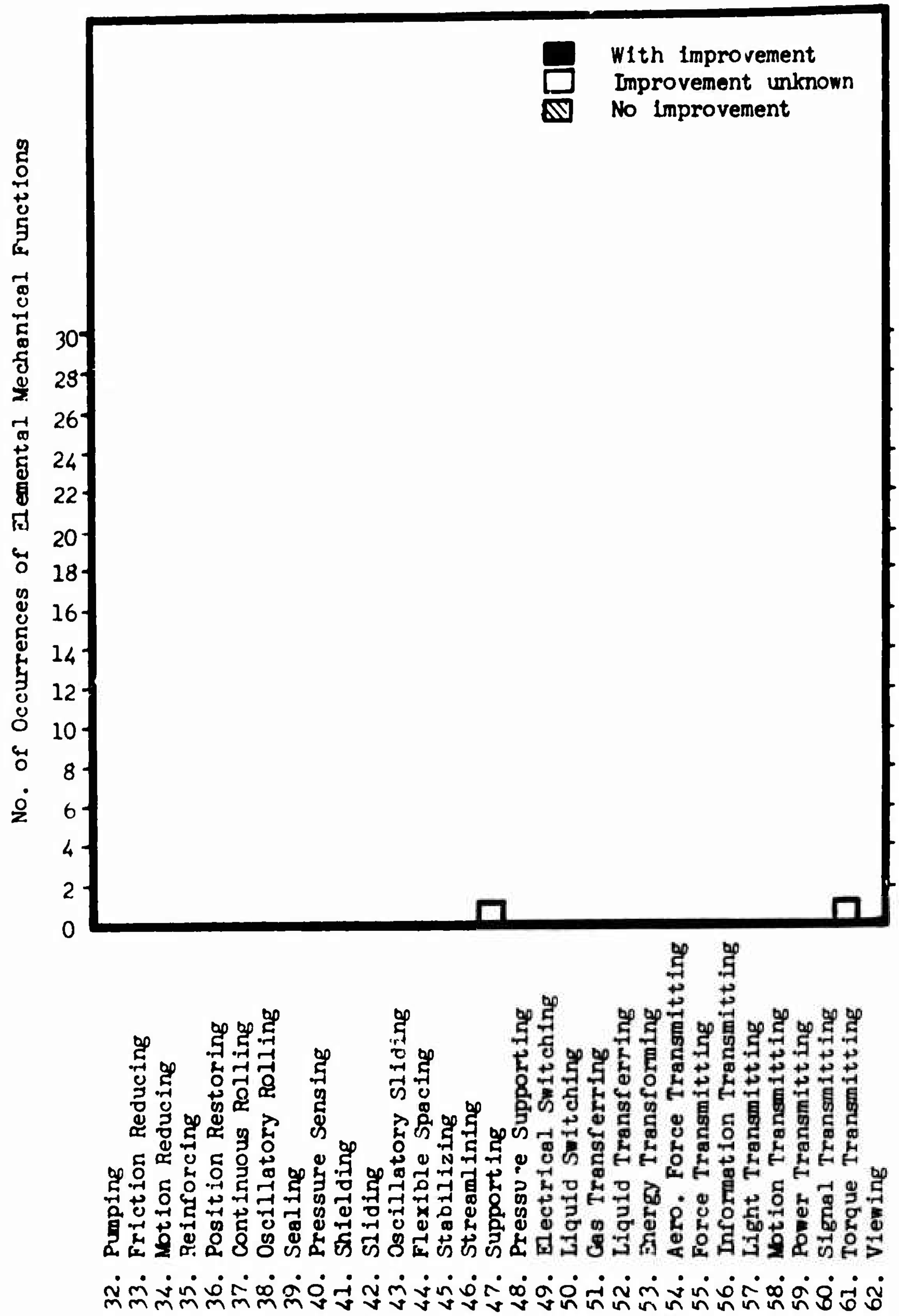


Figure 65. Frequency of Impaired Elemental Functions for the <u>Relaxed Replacement Criteria</u> Corrective Action - Series II.



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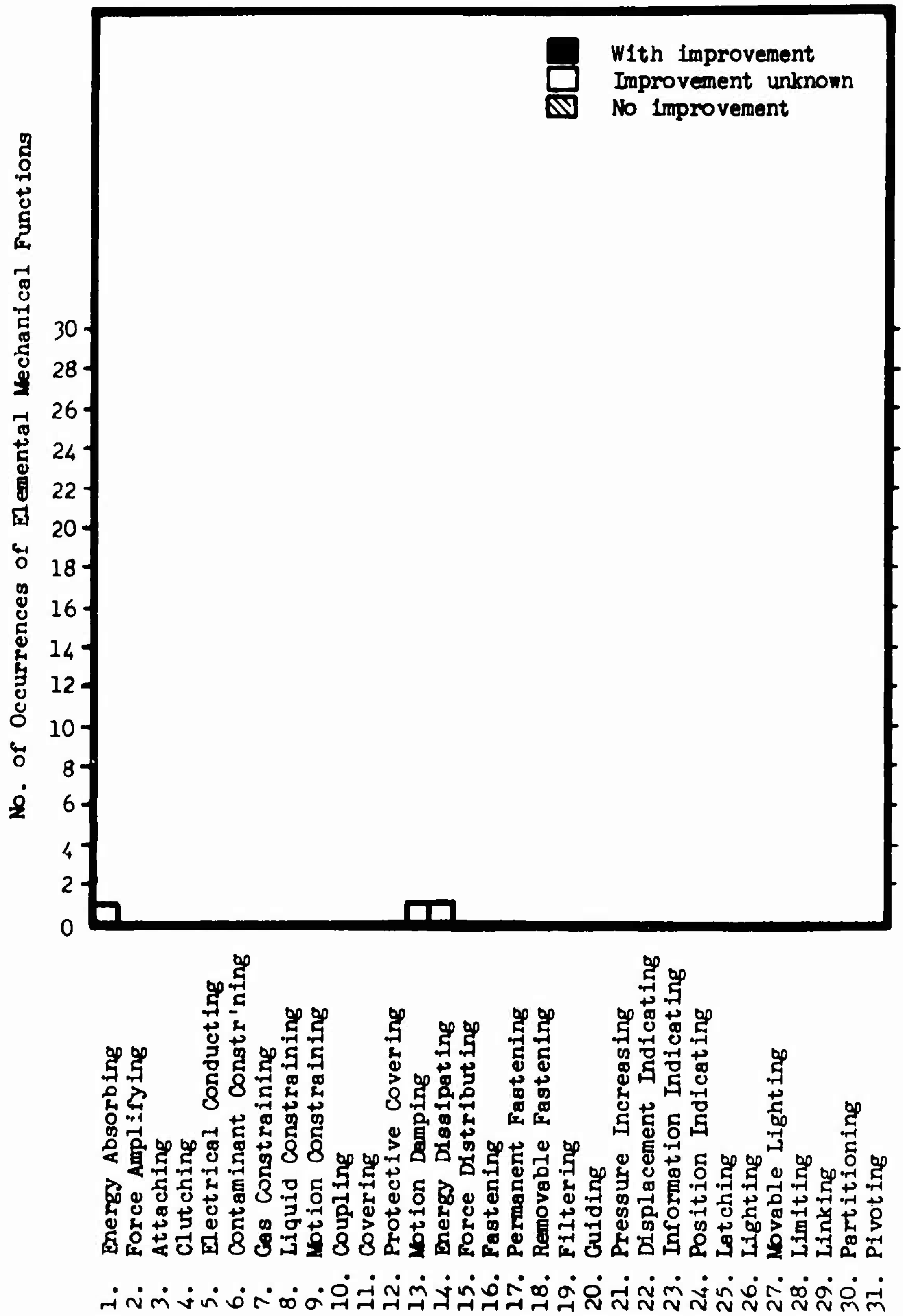
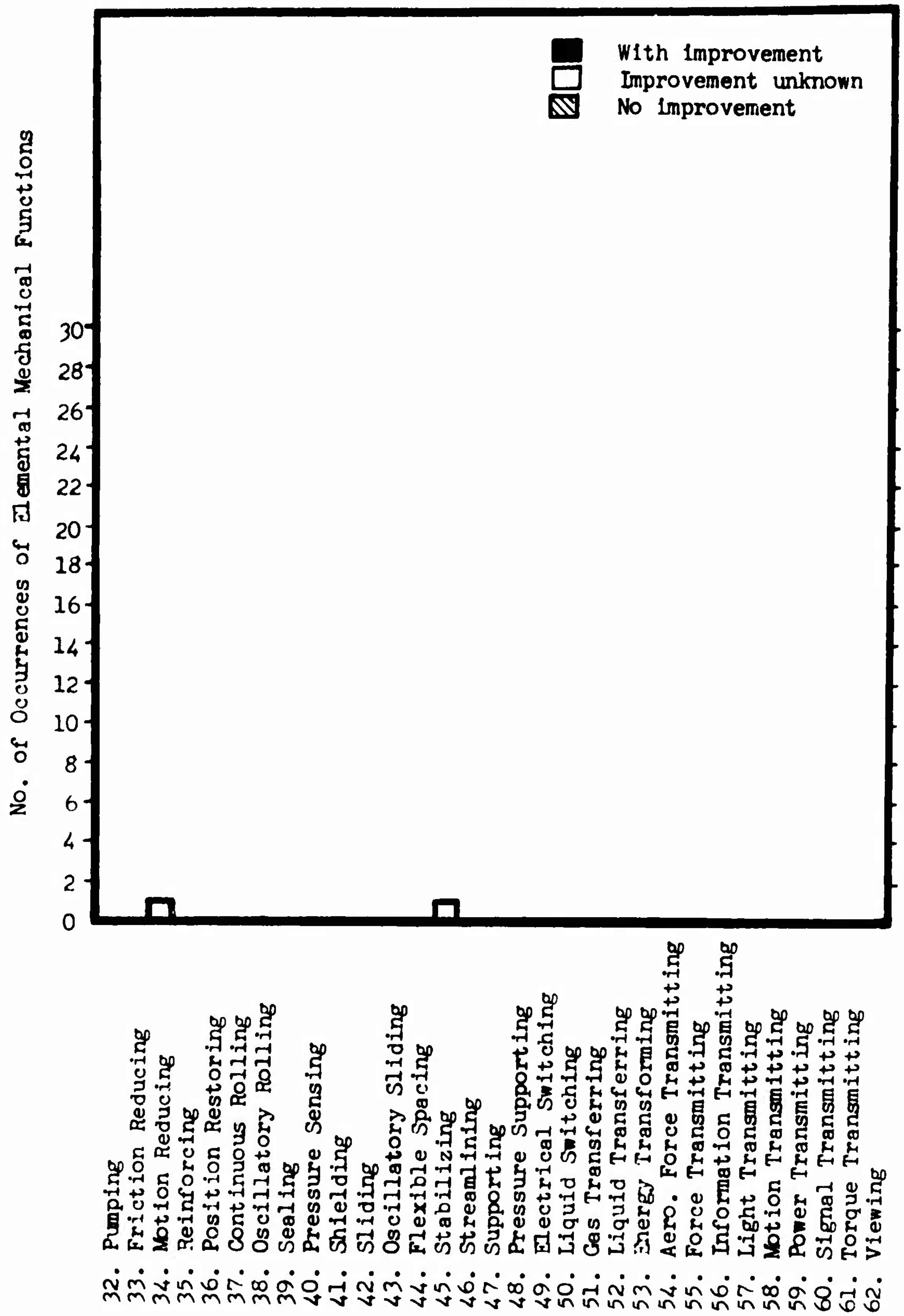


Figure 66. Frequency of Impaired Elemental Functions for the Provided Means for Proper Inspection Corrective Action - Series II.



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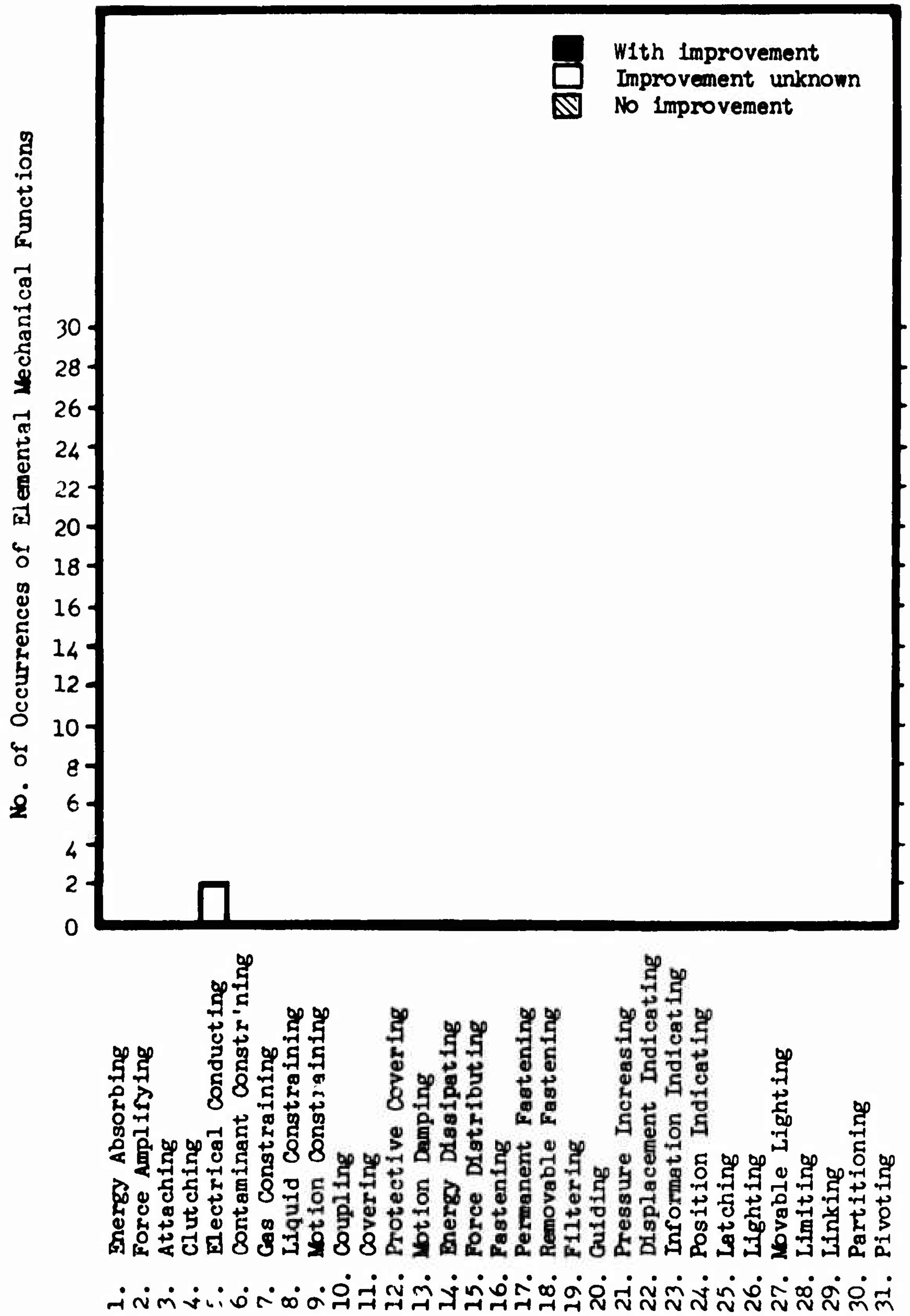
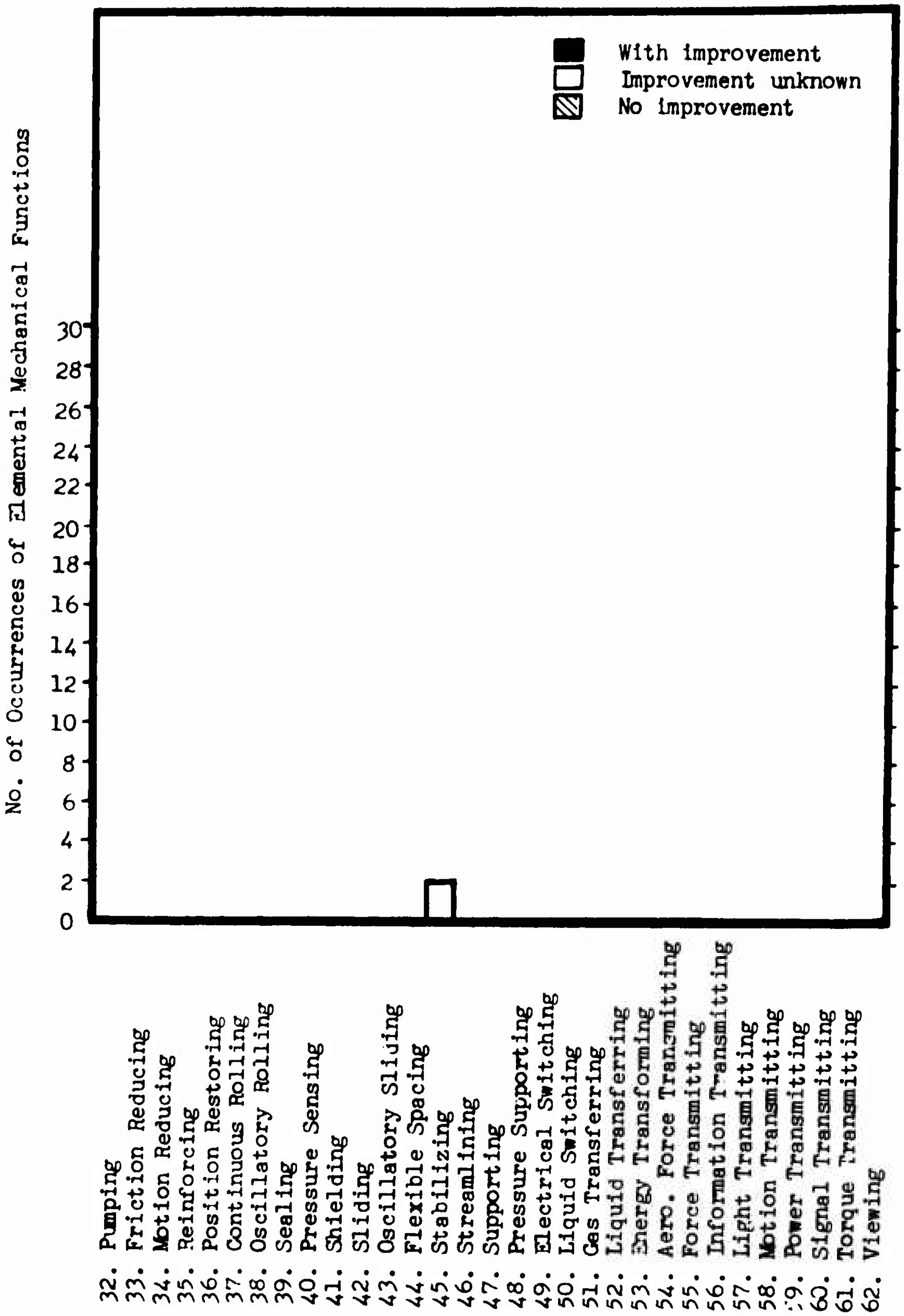


Figure 67. Frequency of Impaired Elemental Functions for the <u>Changed Electrical Characteristics</u> Corrective Action - Series II.



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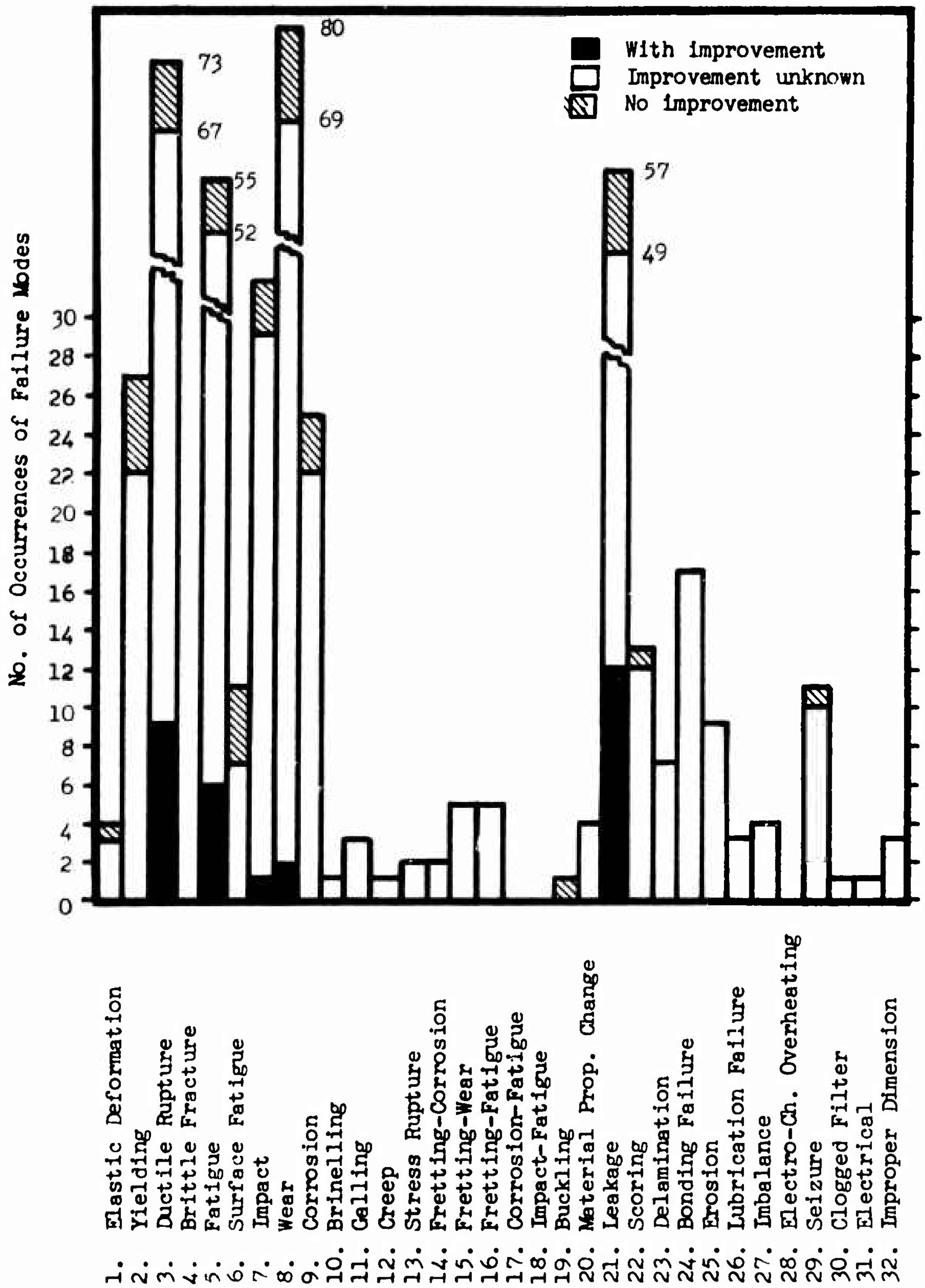

Figure 68. Frequency of Occurrence of Failure Modes for Improved Part Corrective Action - Series III.

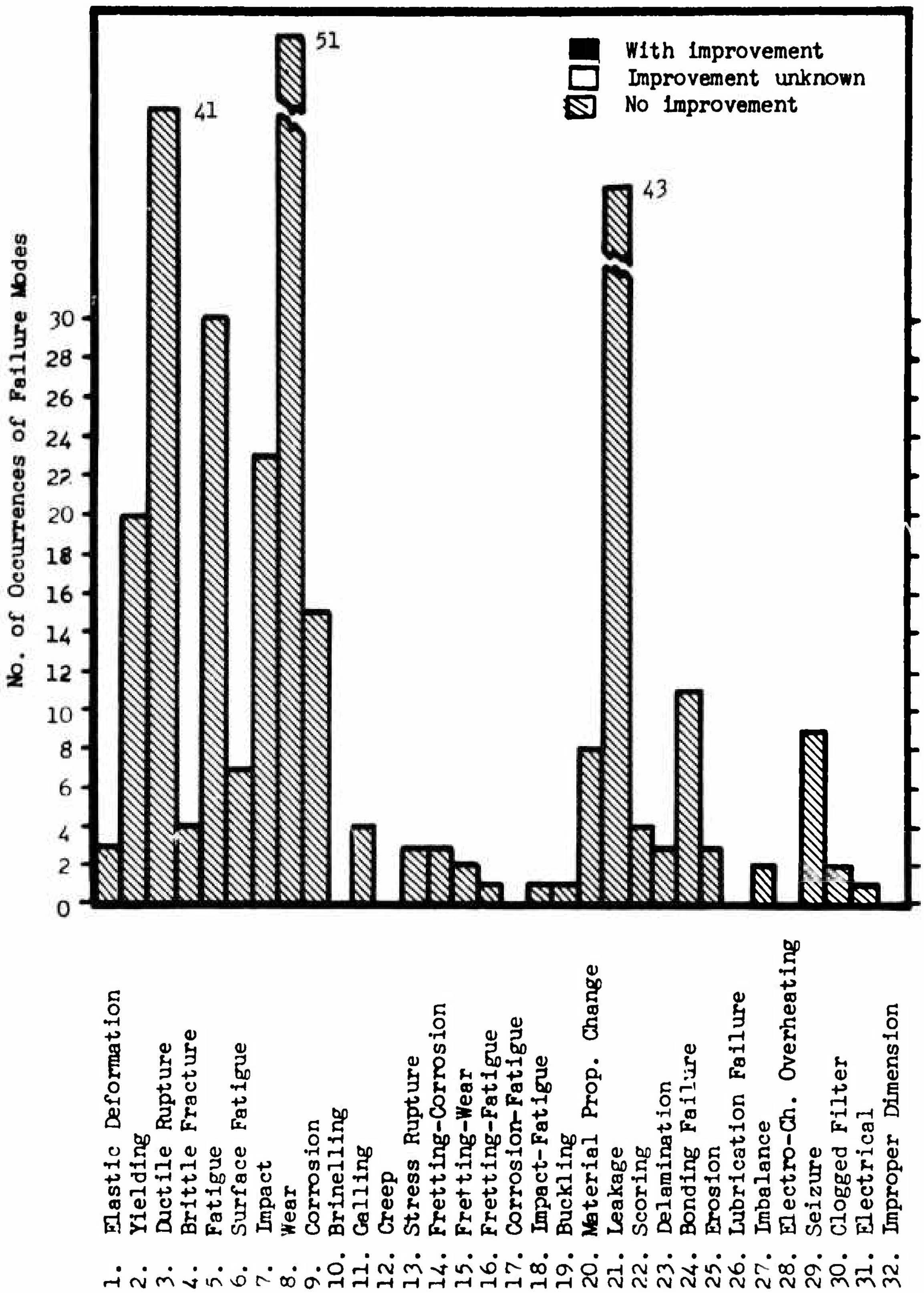

Figure 69. Frequency of Occurrence of Failure Modes for Direct Replacement Corrective Action - Series III.

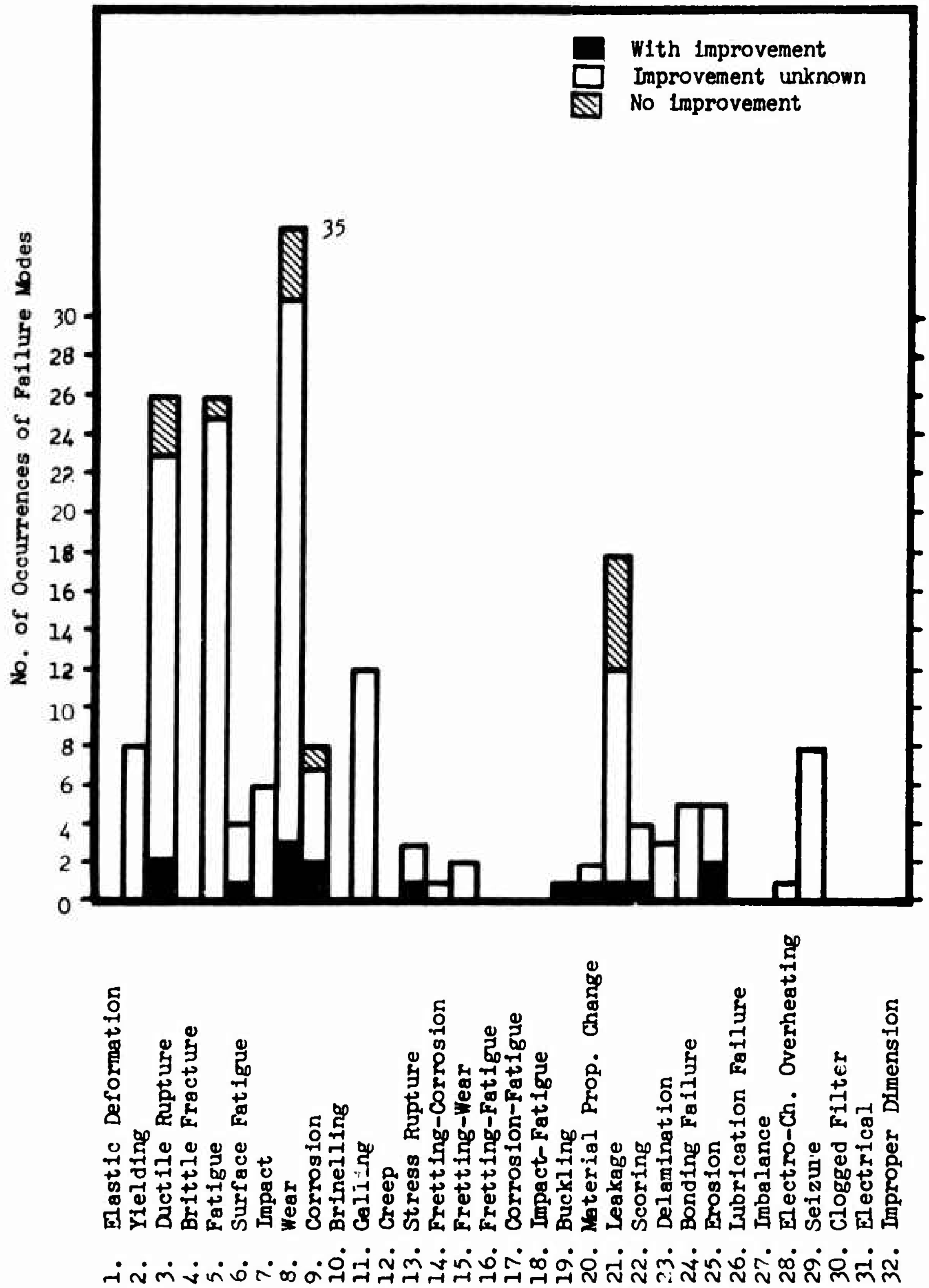

Figure 70. Frequency of Occurrence of Failure Modes for Change of Material Corrective Action - Series III.

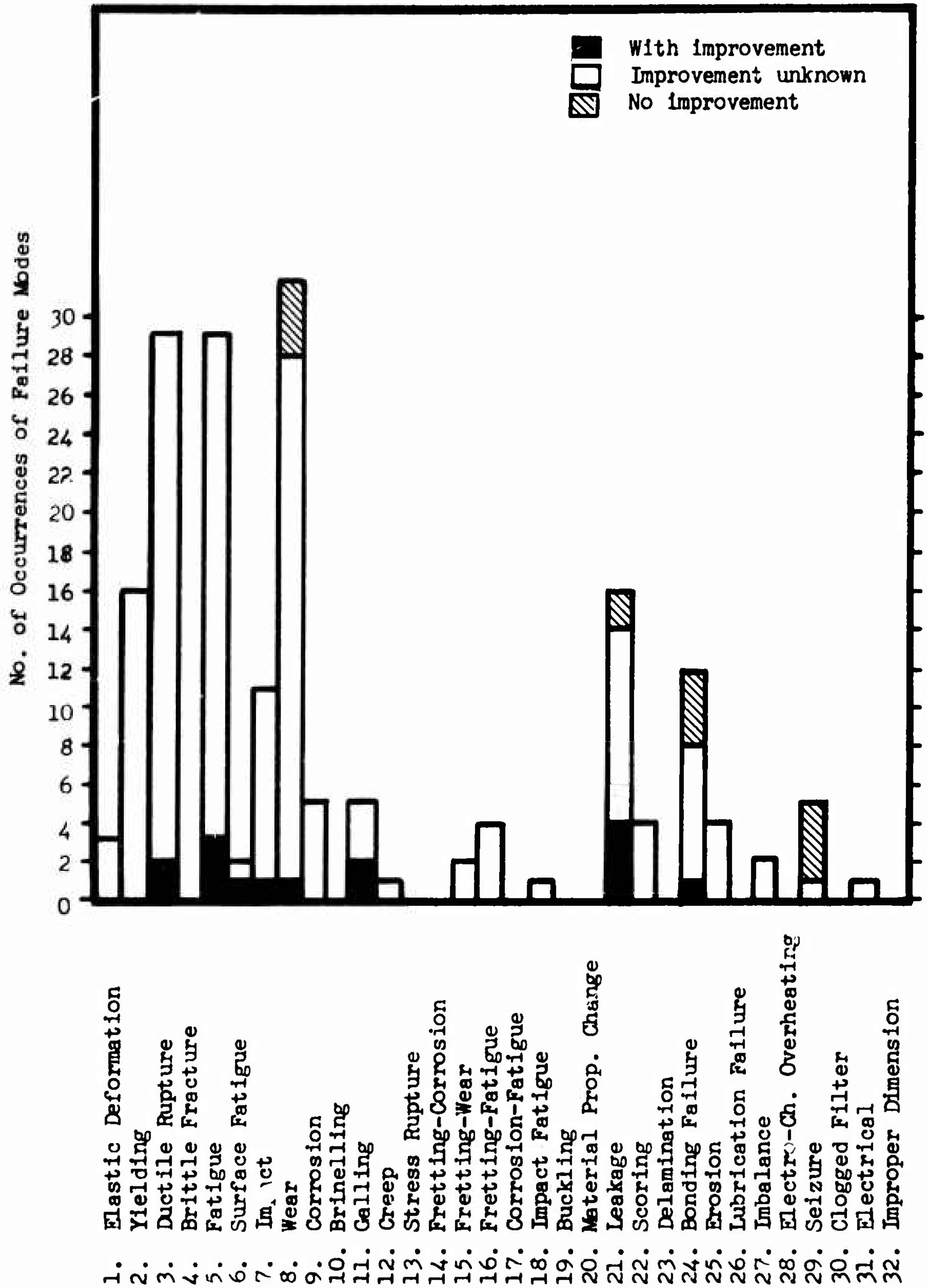

Figure 71. Frequency of Occurrence of Failure Modes for <u>Supplemental Part</u> Corrective Action - Series III.

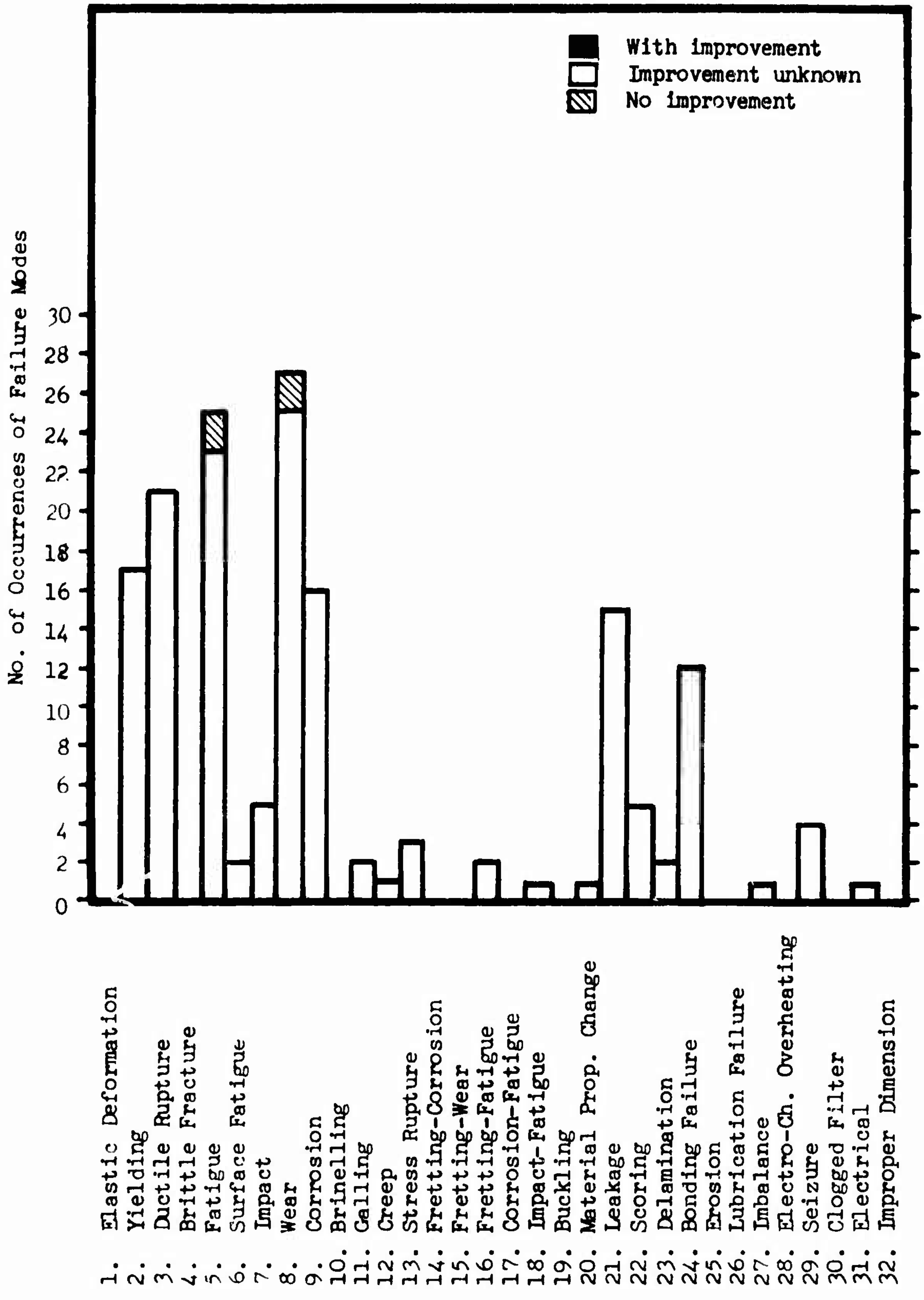

Figure 72. Frequency of Occurrence of Failure Modes for <u>Improved Instructions to Field Personnel</u> Corrective Action - Series III.

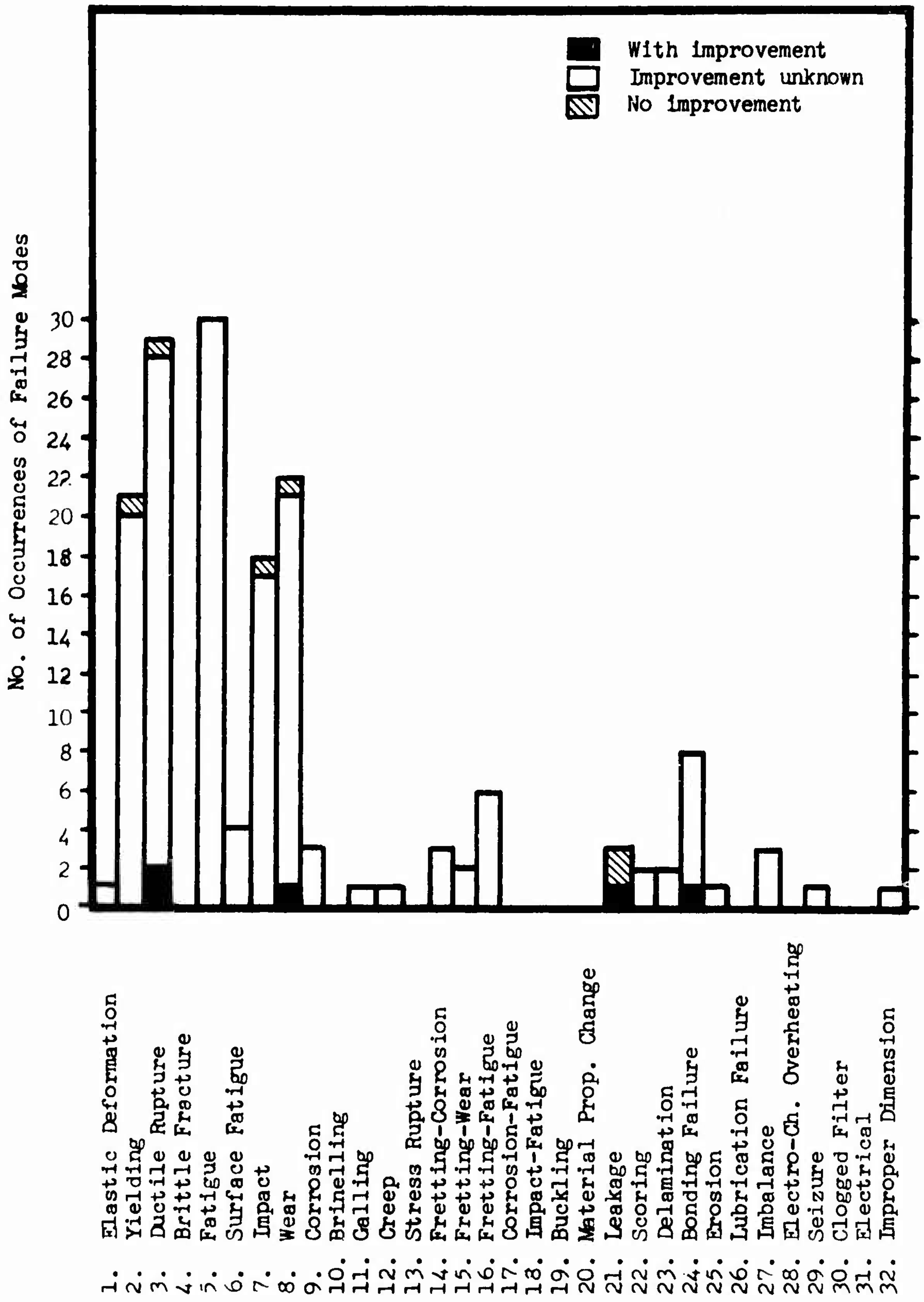

Figure 73. Frequency of Occurrence of Failure Modes for Changed Dimensions Corrective Action - Series III.

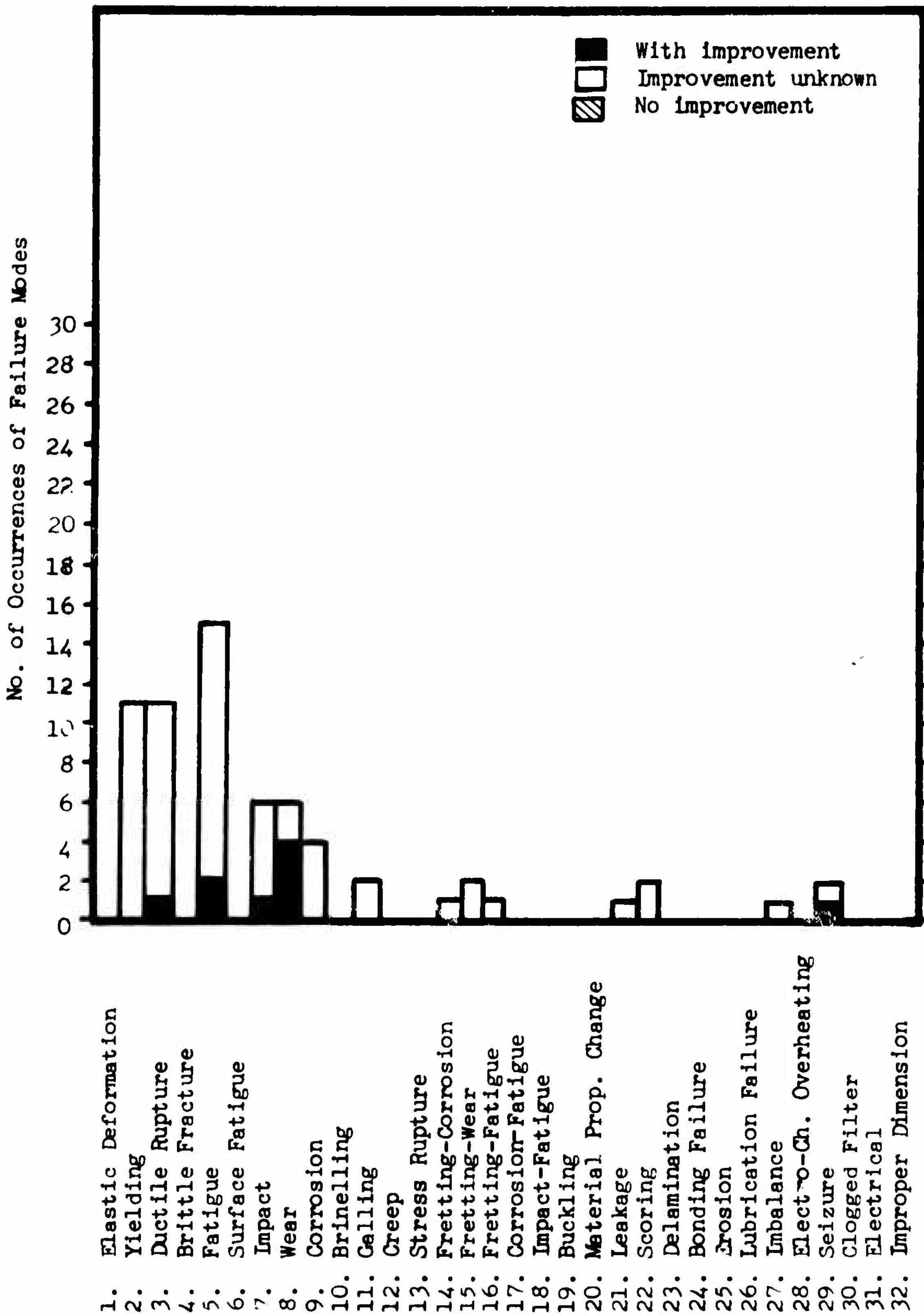

Figure 74. Frequency of Occurrence of Failure Modes for Changed Loading on Part Corrective Action - Series III.

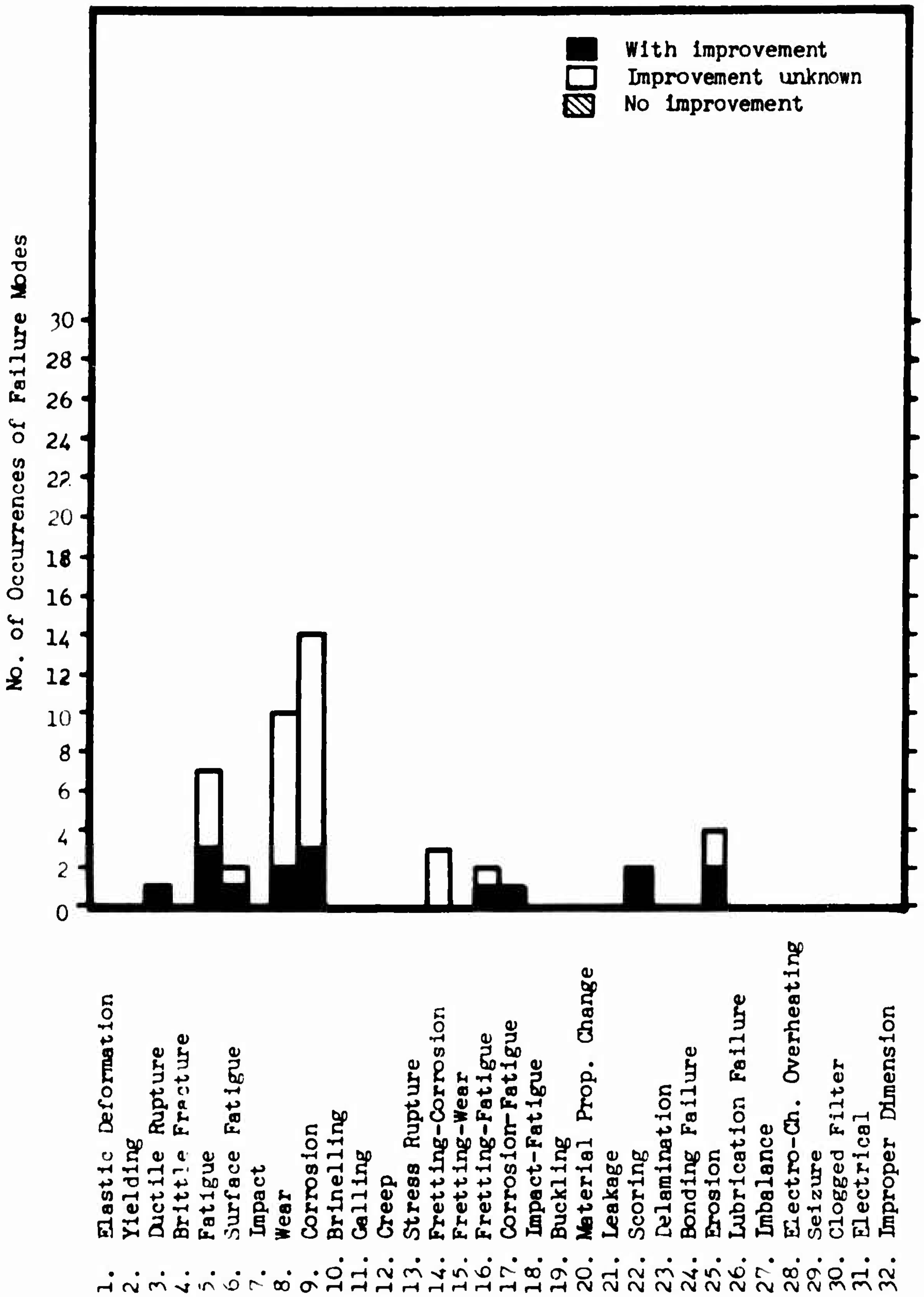

Figure 75. Frequency of Occurrence of Failure Modes for Applied Surface Coating Corrective Action - Series III.

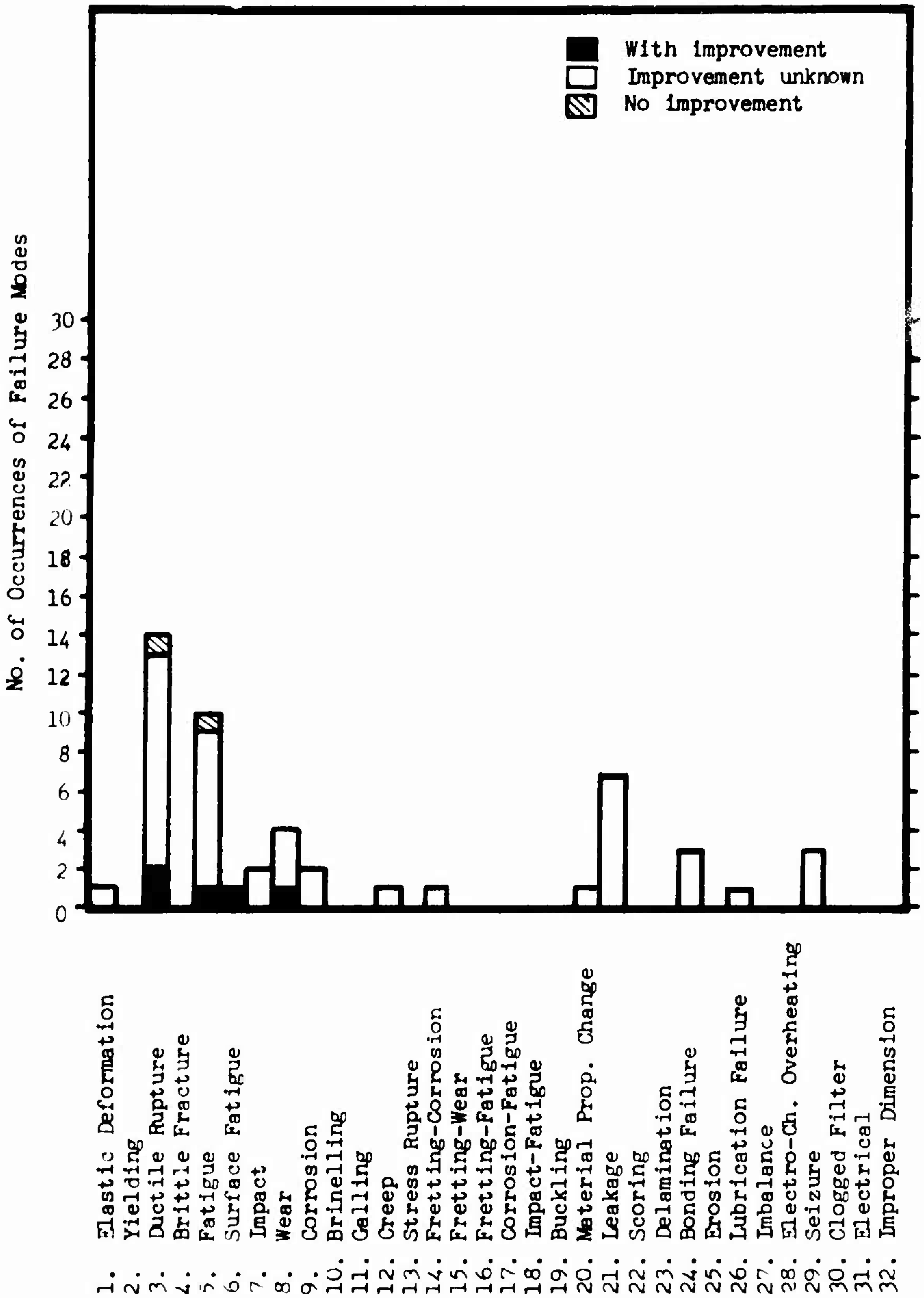

Figure 76. Frequency of Occurrence of Failure Modes for Changed Mechanism of Operation Corrective Action - Series III.

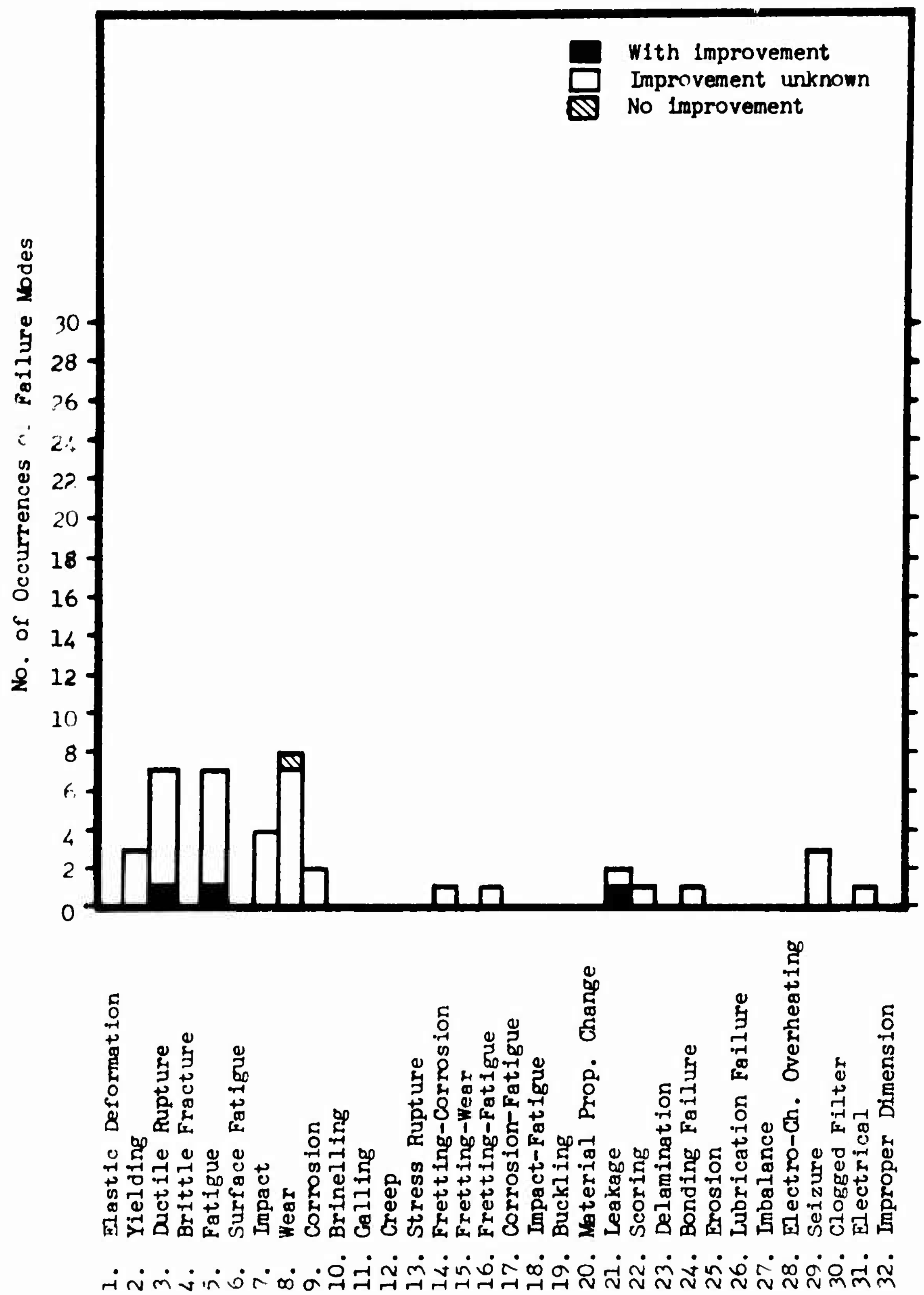

Figure 77. Frequency of Occurrence of Failure Modes for Relocated or Repositioned Part Corrective Action - Series III.

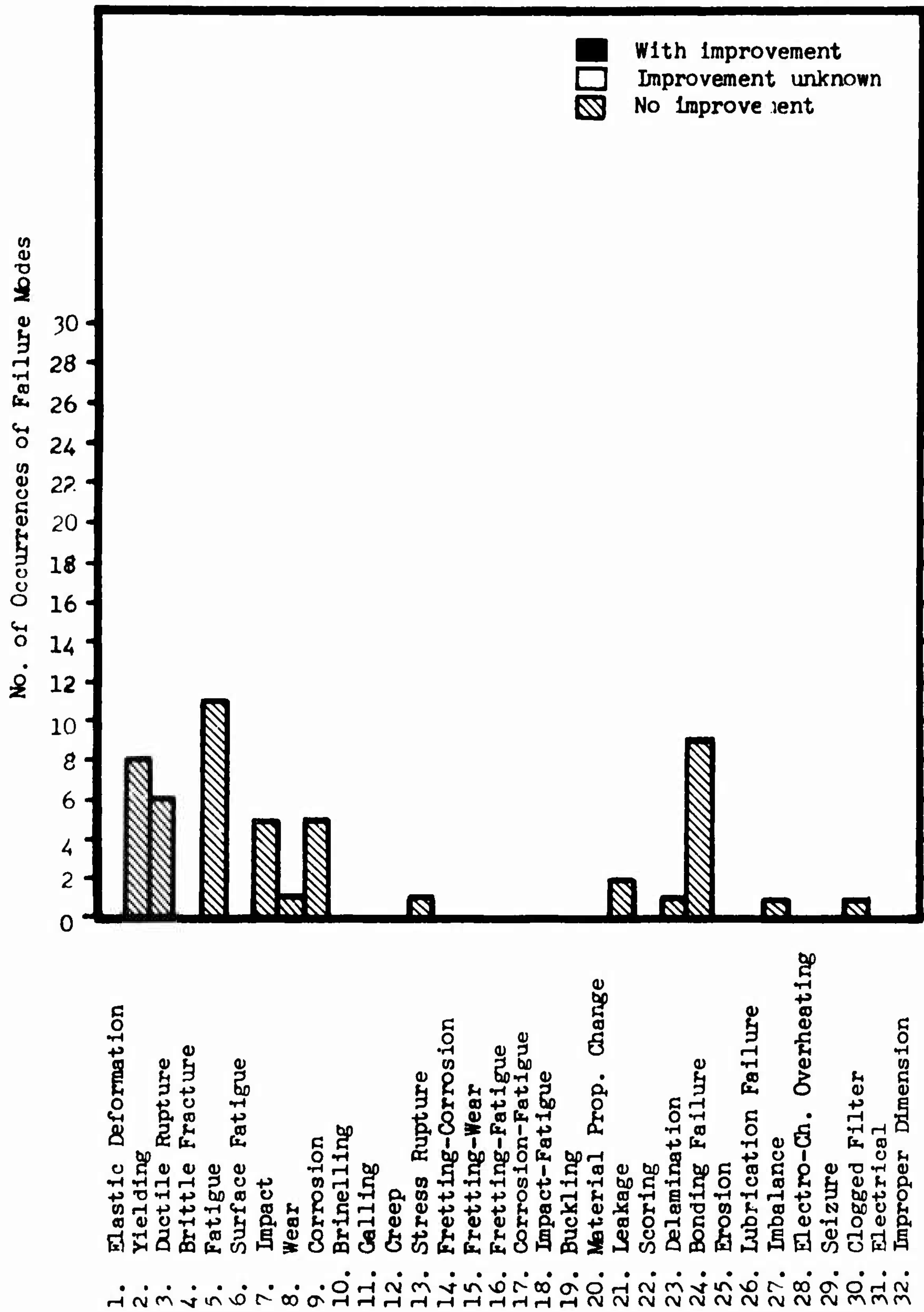

Figure 78. Frequency of Occurrence of Failure Modes for <u>Repaired</u> Corrective Action - Series III.

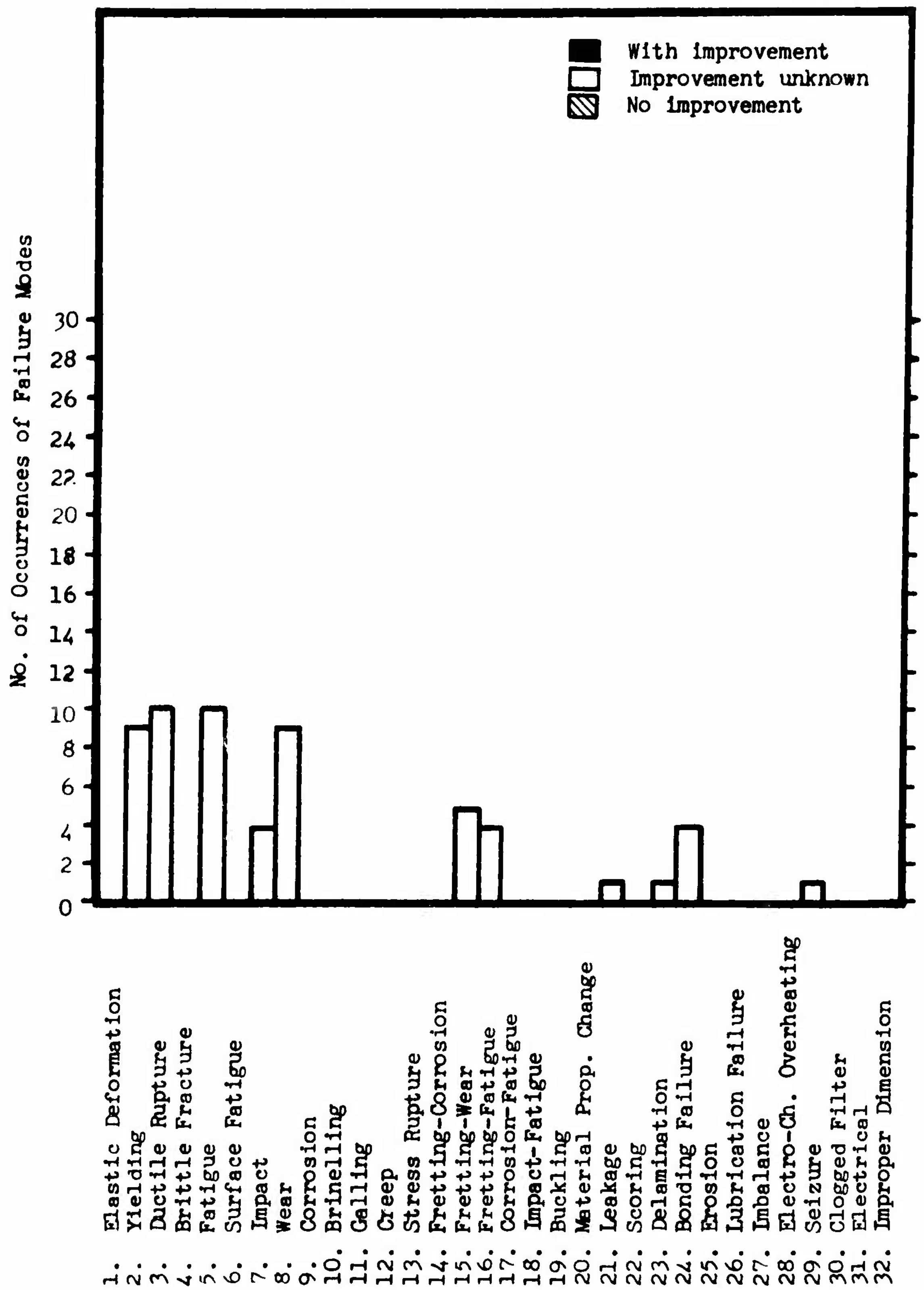

Figure 79. Frequency of Occurrence of Failure Modes for Changed Method of Attachment Corrective Action - Series III.

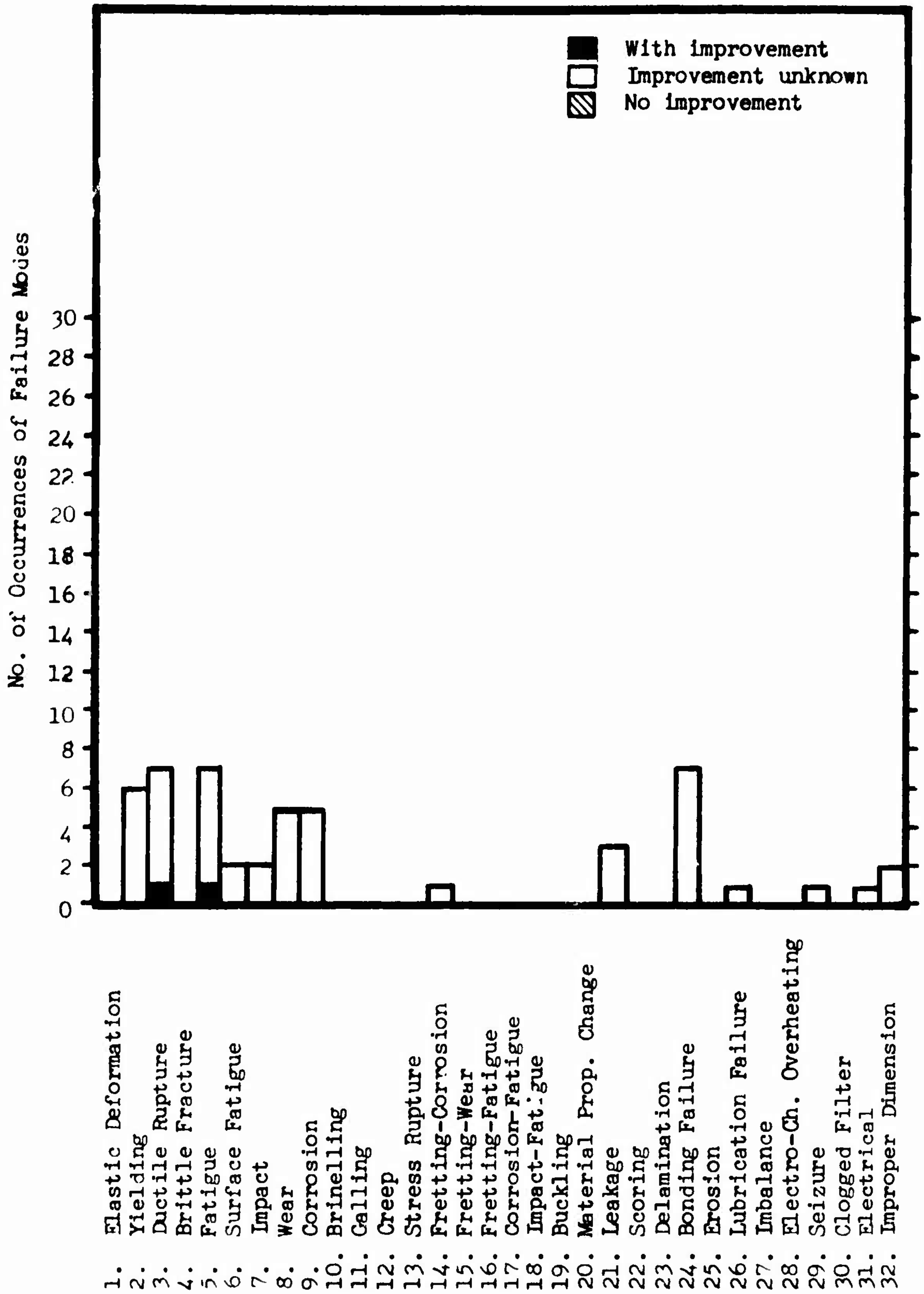

Figure 80. Frequency of Occurrence of Failure Modes for Changed Manufacturing Procedure Corrective Action - Series III.

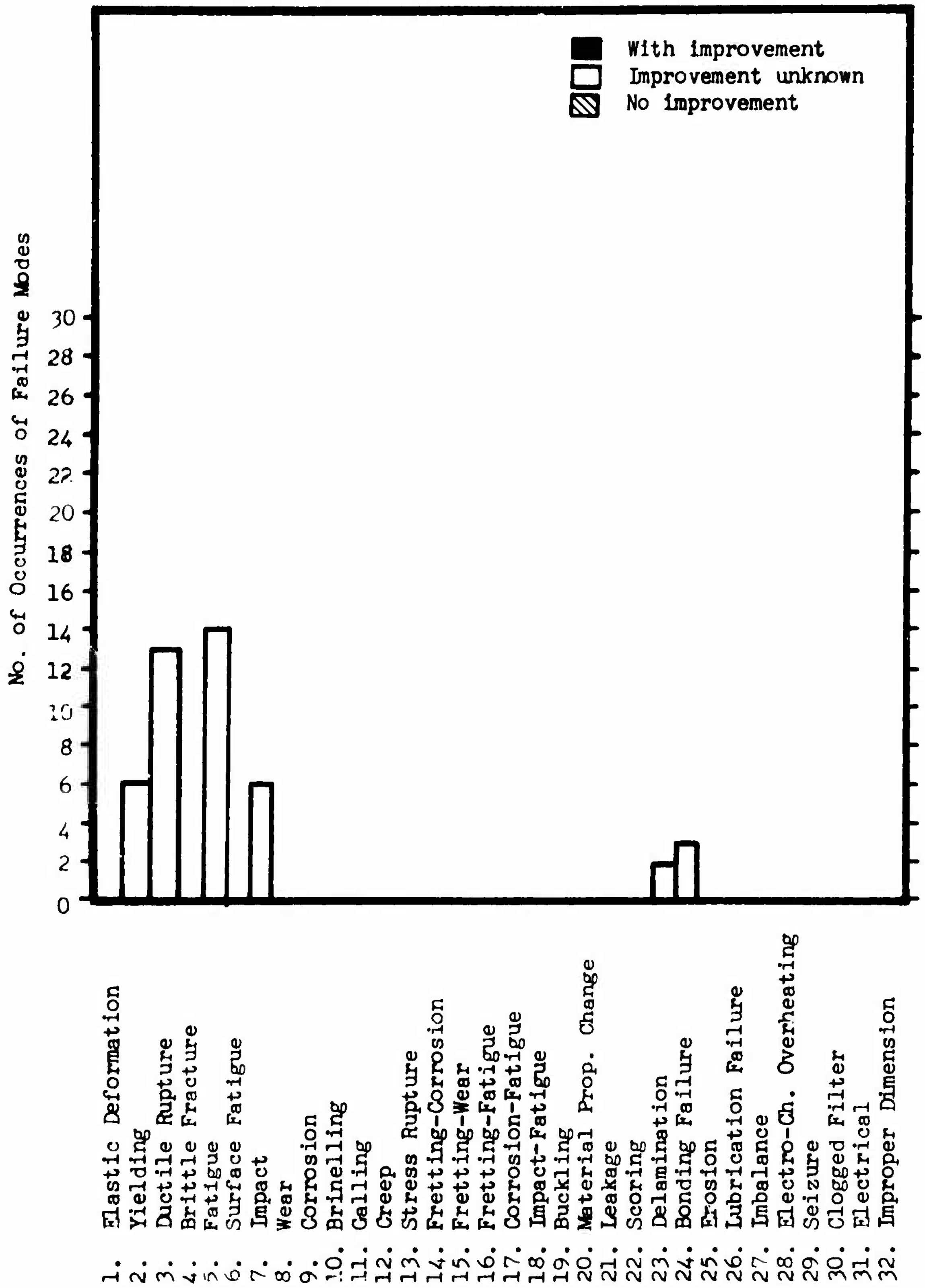

Figure 81. Frequency of Occurrence of Failure Modes for Reinforced Part Corrective Action - Series III.

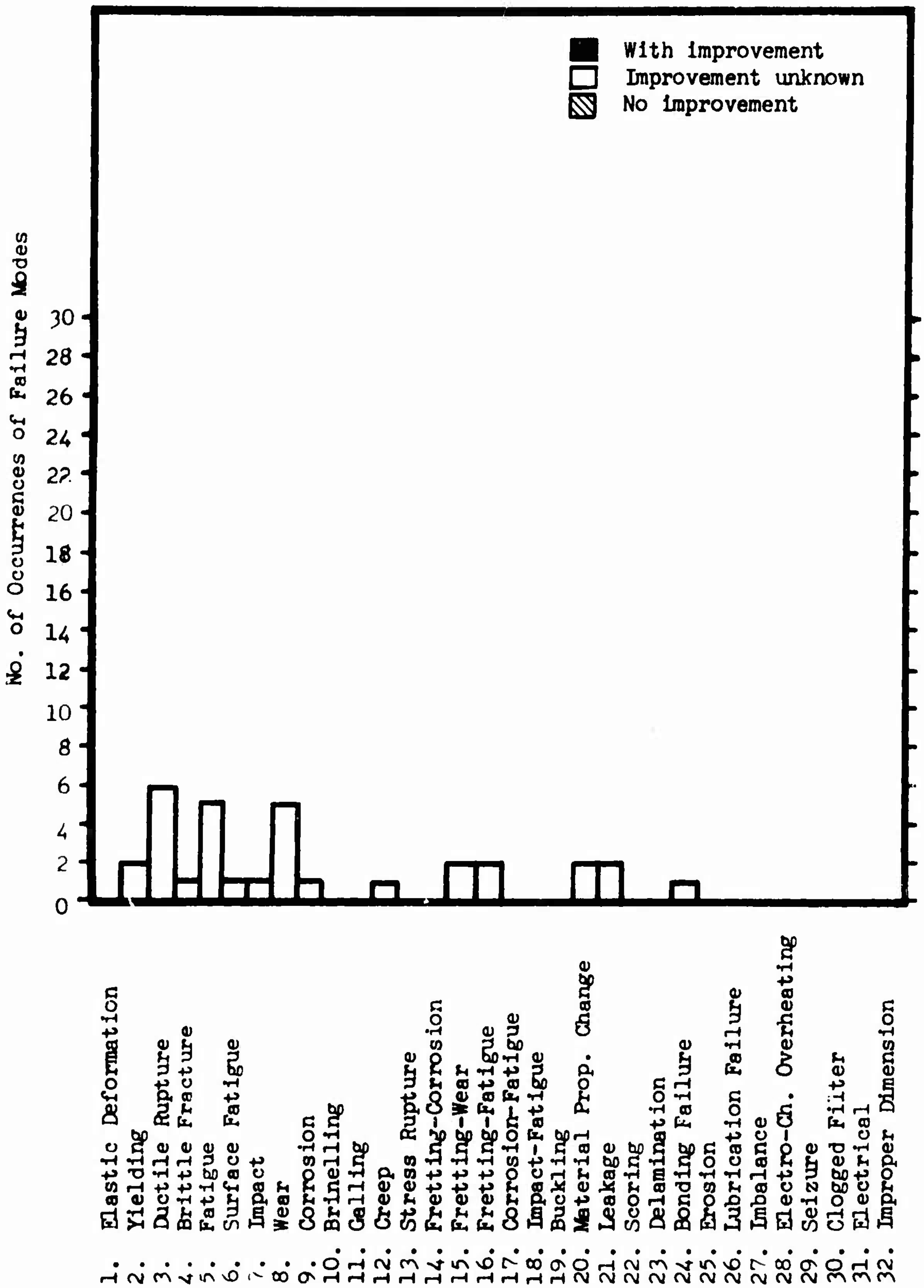

Figure 82. Frequency of Occurrence of Failure Modes for Eliminated Part Corrective Action - Series III.

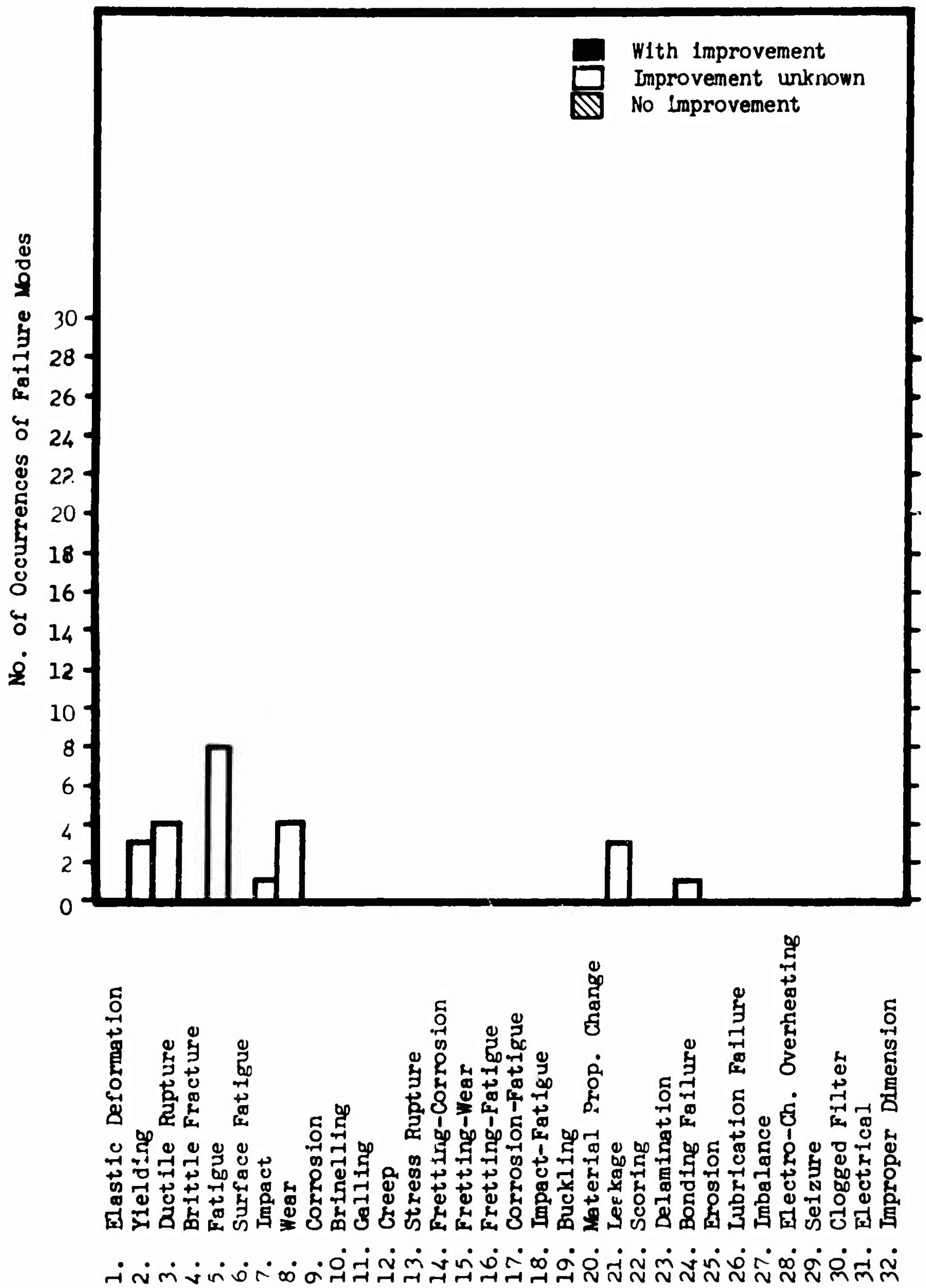

Figure 83. Frequency of Occurrence of Failure Modes for <u>Strengthened Part</u> Corrective Action - Series III.

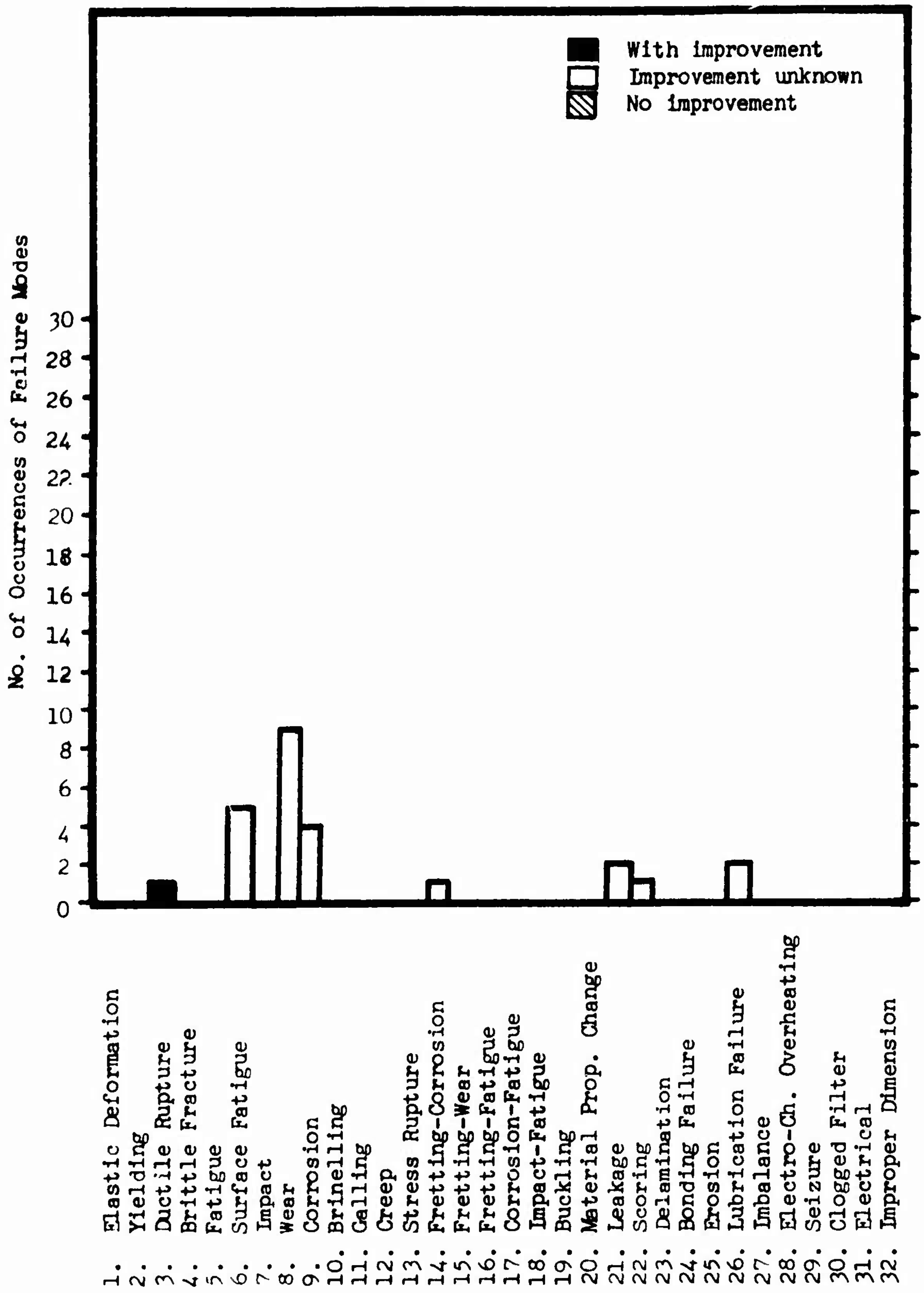

Figure 84. Frequency of Occurrence of Failure Modes for Changed Method or Frequency of Lubrication Corrective Action - Series III.

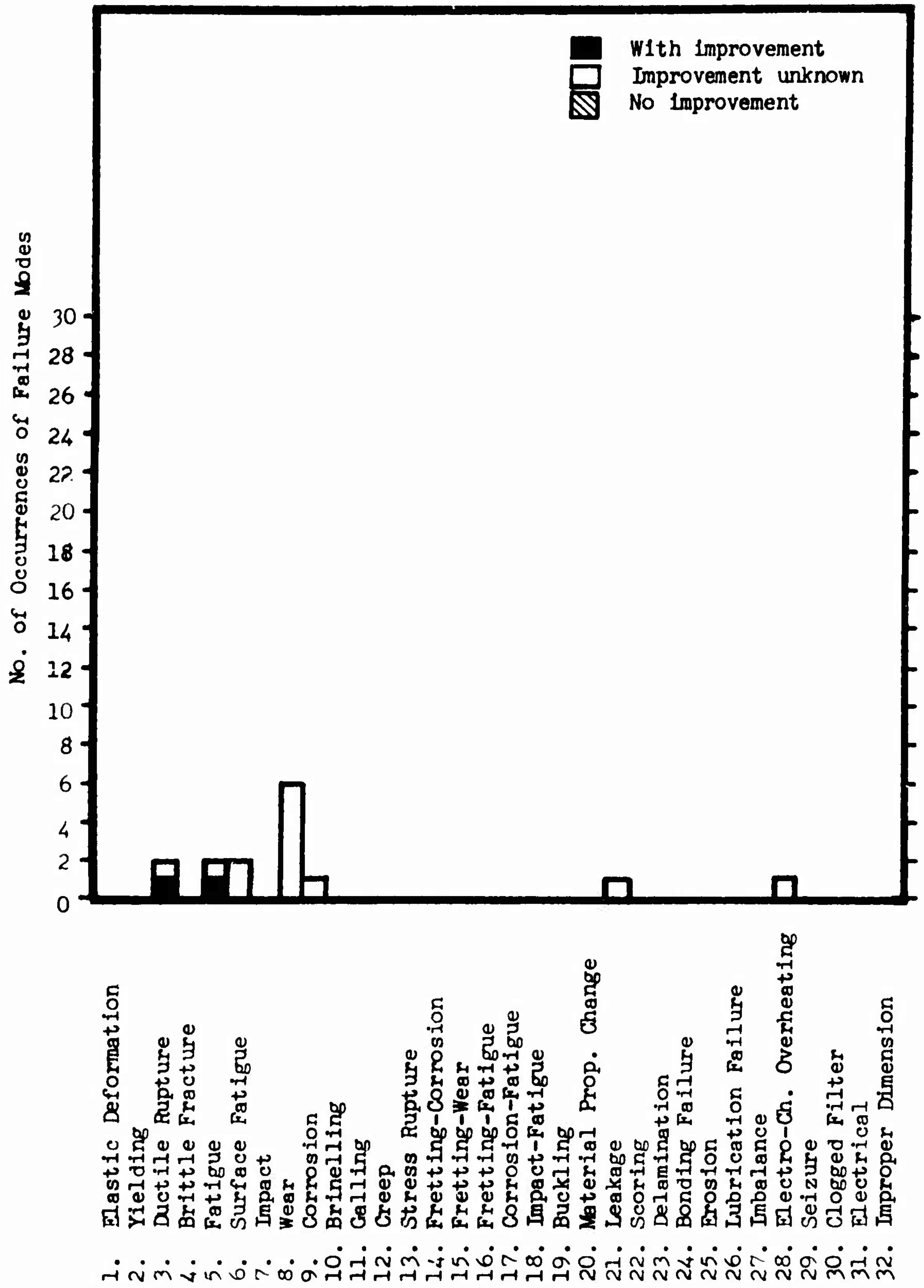

Figure 85. Frequency of Occurrence of Failure Modes for Changed Vendor Corrective Action - Series III.

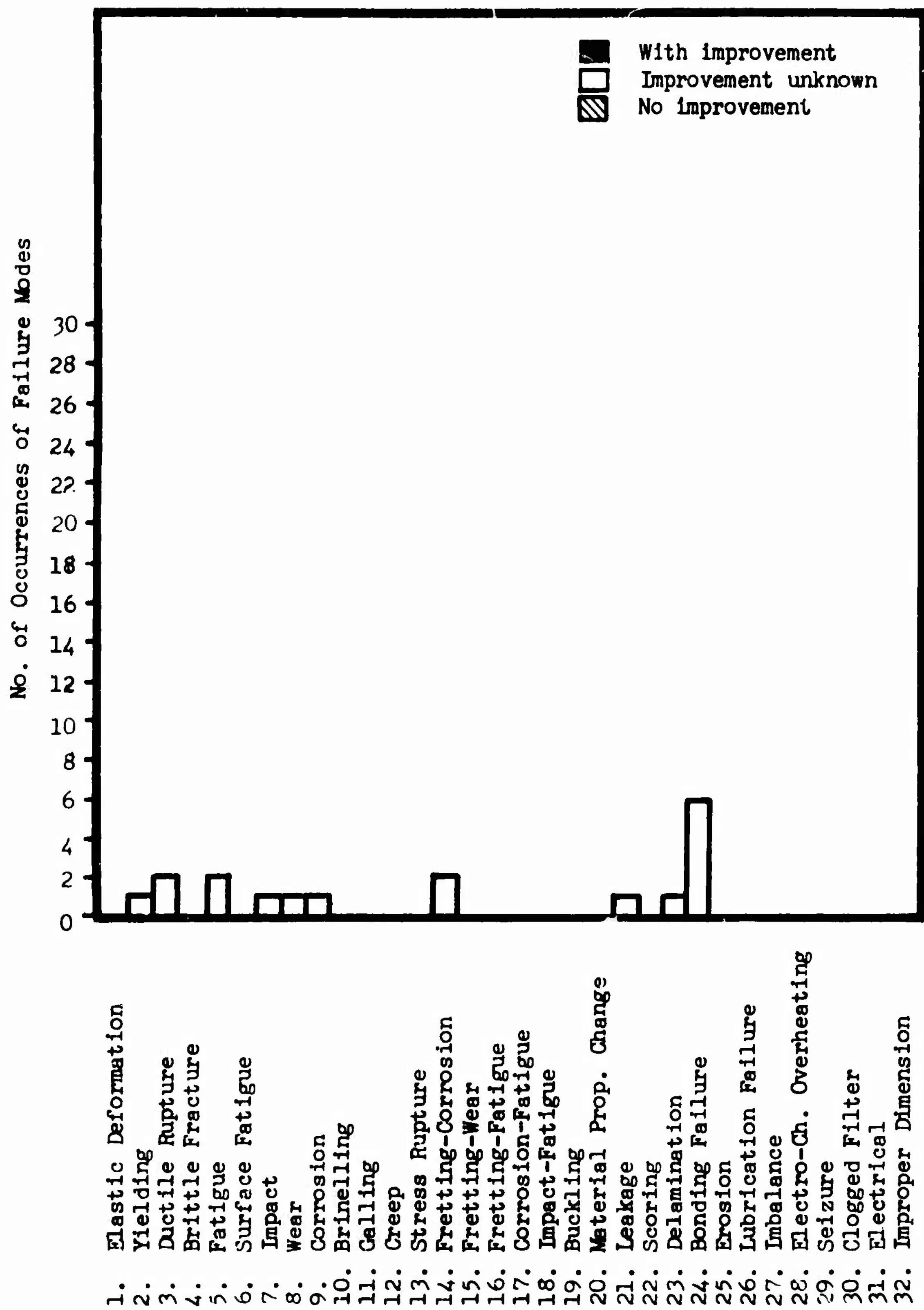

Figure 86. Frequency of Occurrence of Failure Modes for Added or Changed Adhesive Material Corrective Action - Series III.

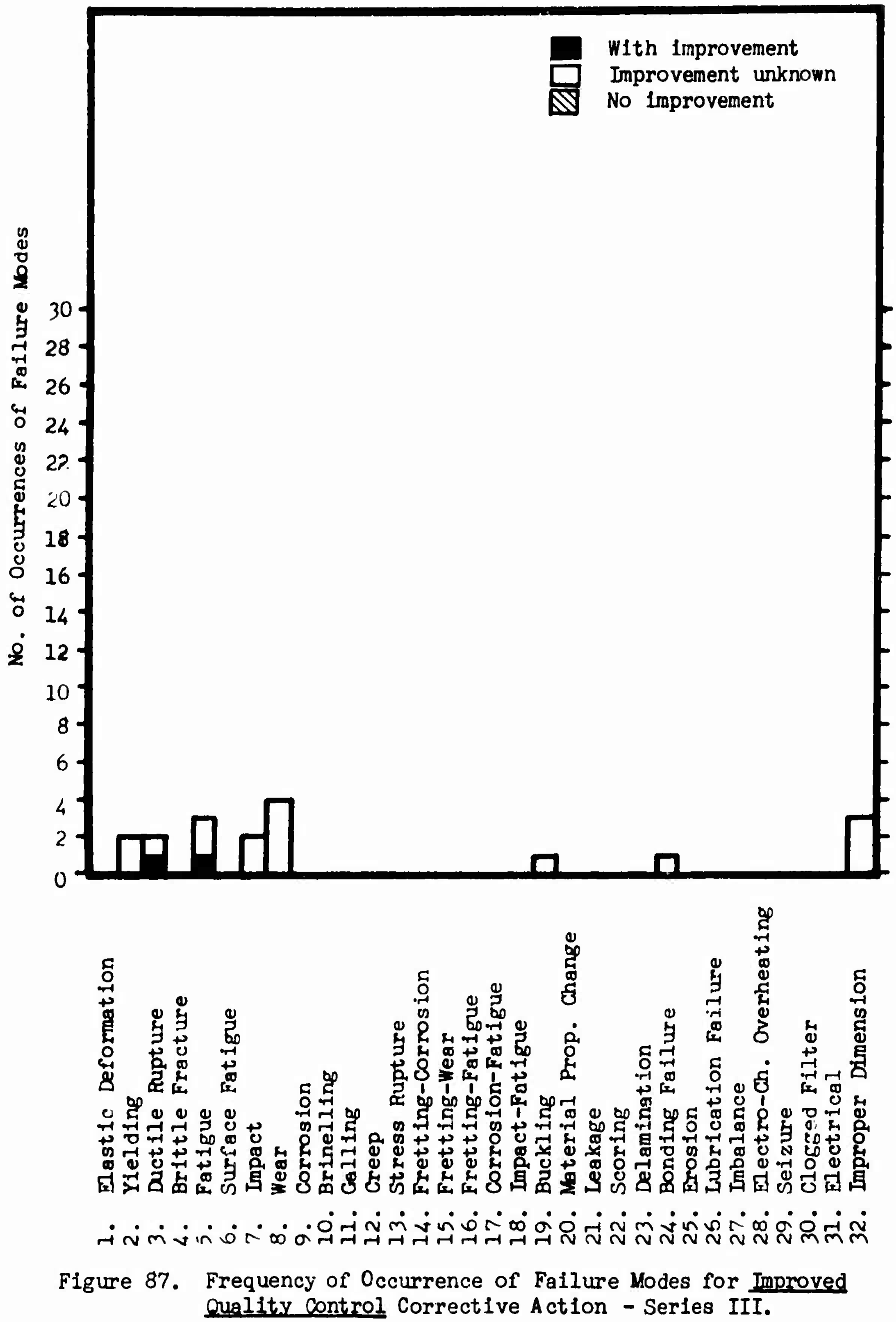

Figure 87. Frequency of Occurrence of Failure Modes for Improved Quality Control Corrective Action - Series III.

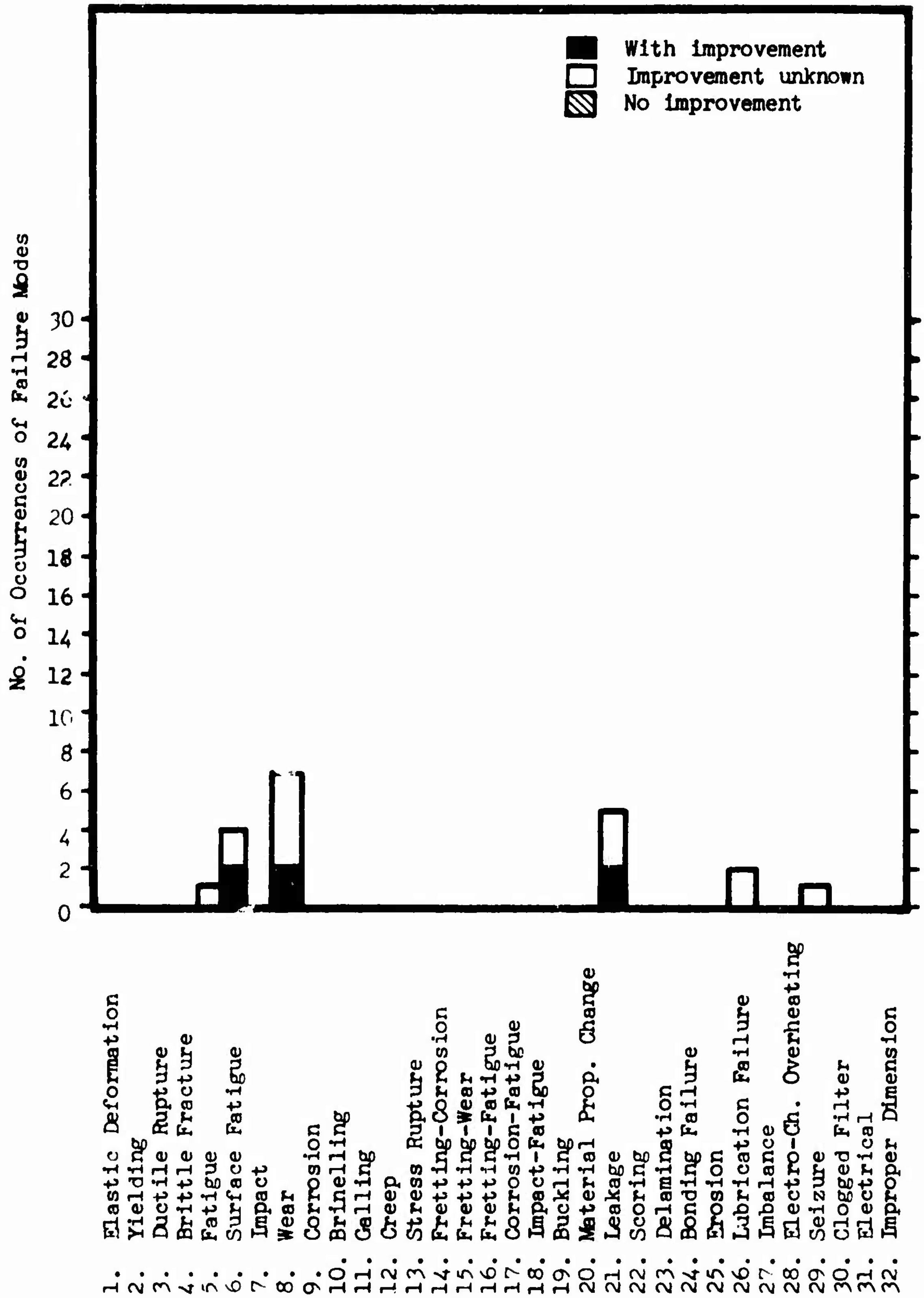

Figure 88. Frequency of Occurrence of Failure Modes for Changed Type or Added Lubricant Corrective Action - Series III.

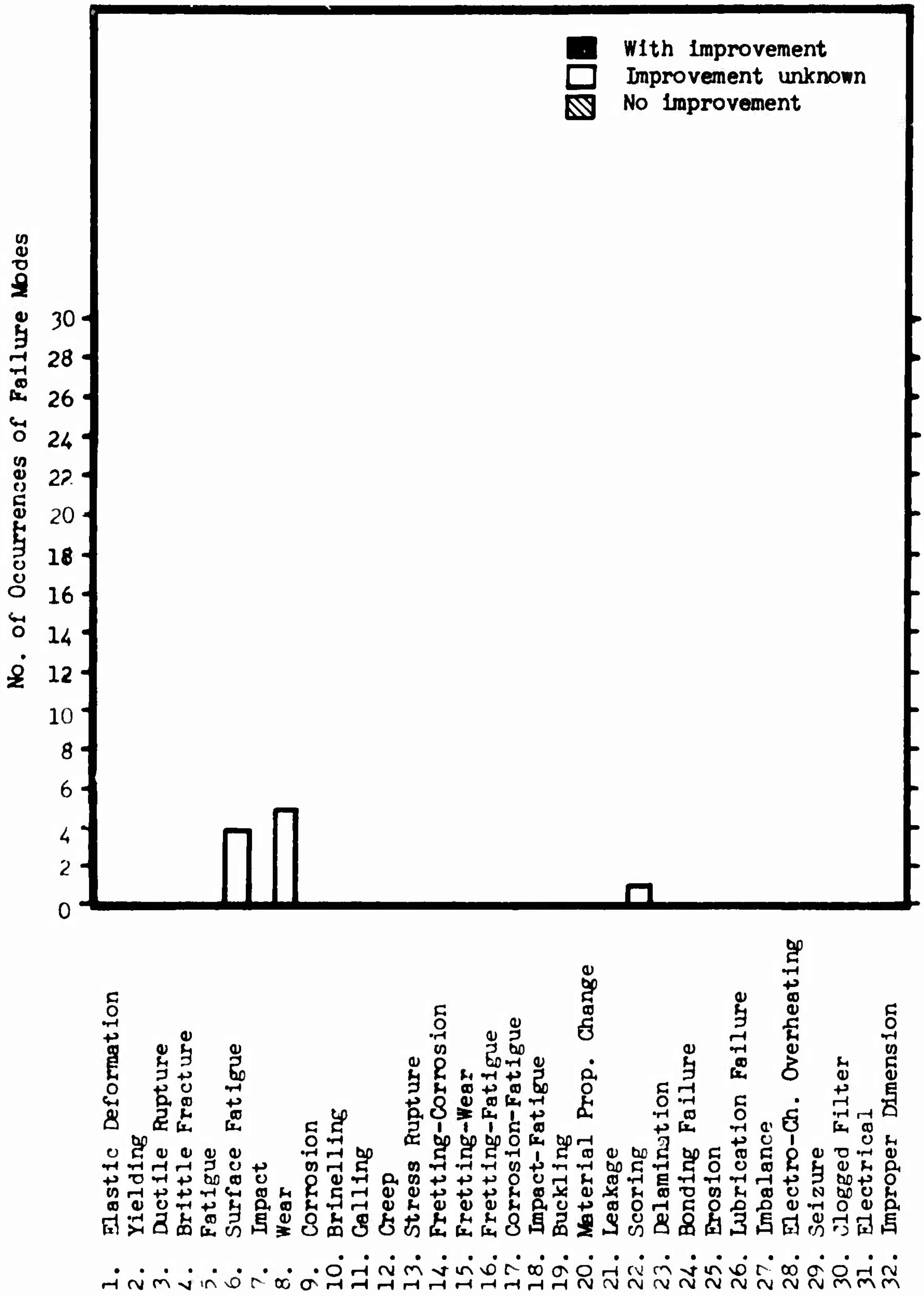

Figure 89. Frequency of Occurrence of Failure Modes for Improved Run-In Procedure Corrective Action - Series III.

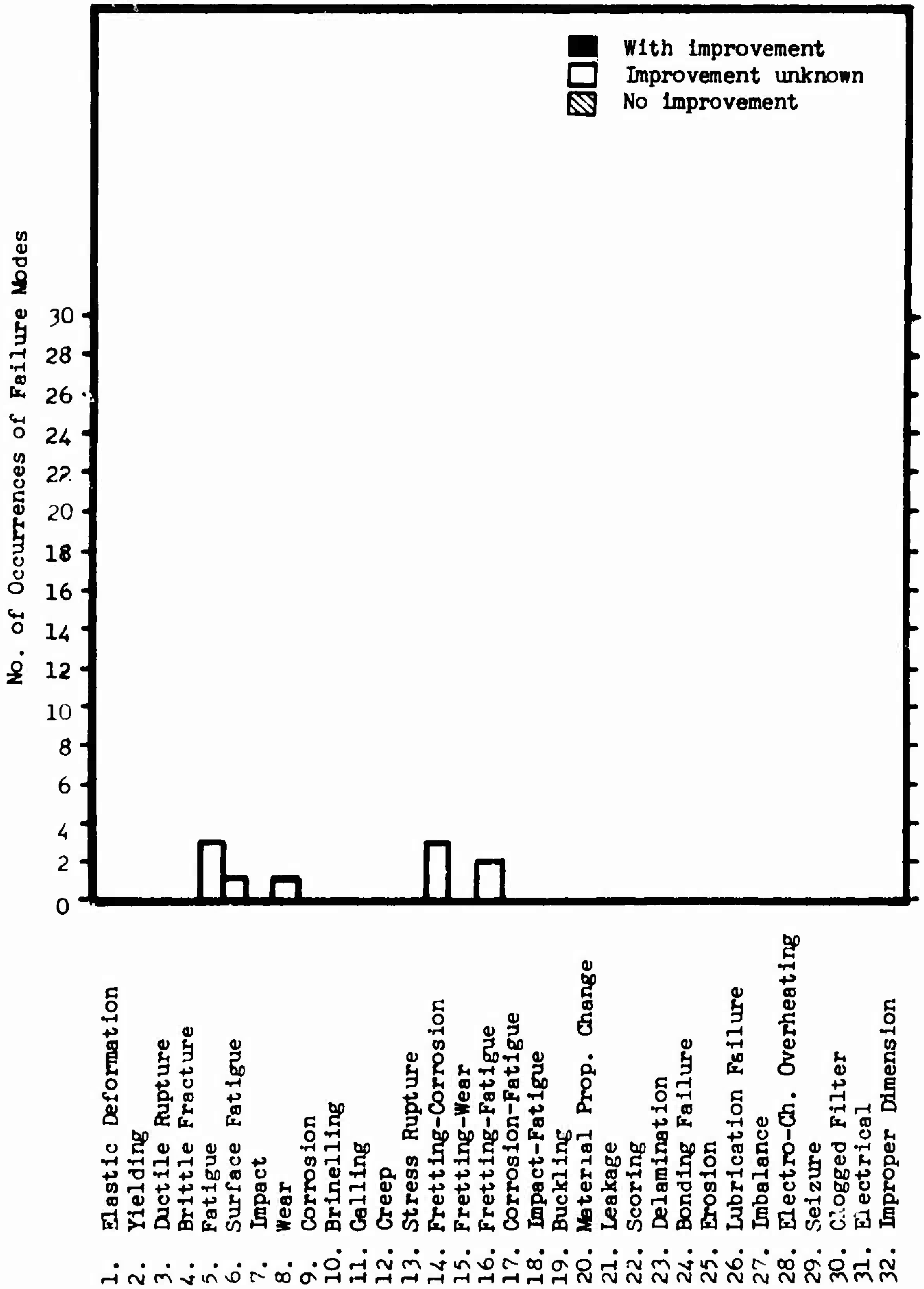

Figure 90. Frequency of Occurrence of Failure Modes for Applied Surface Treatment Corrective Action - Series III.

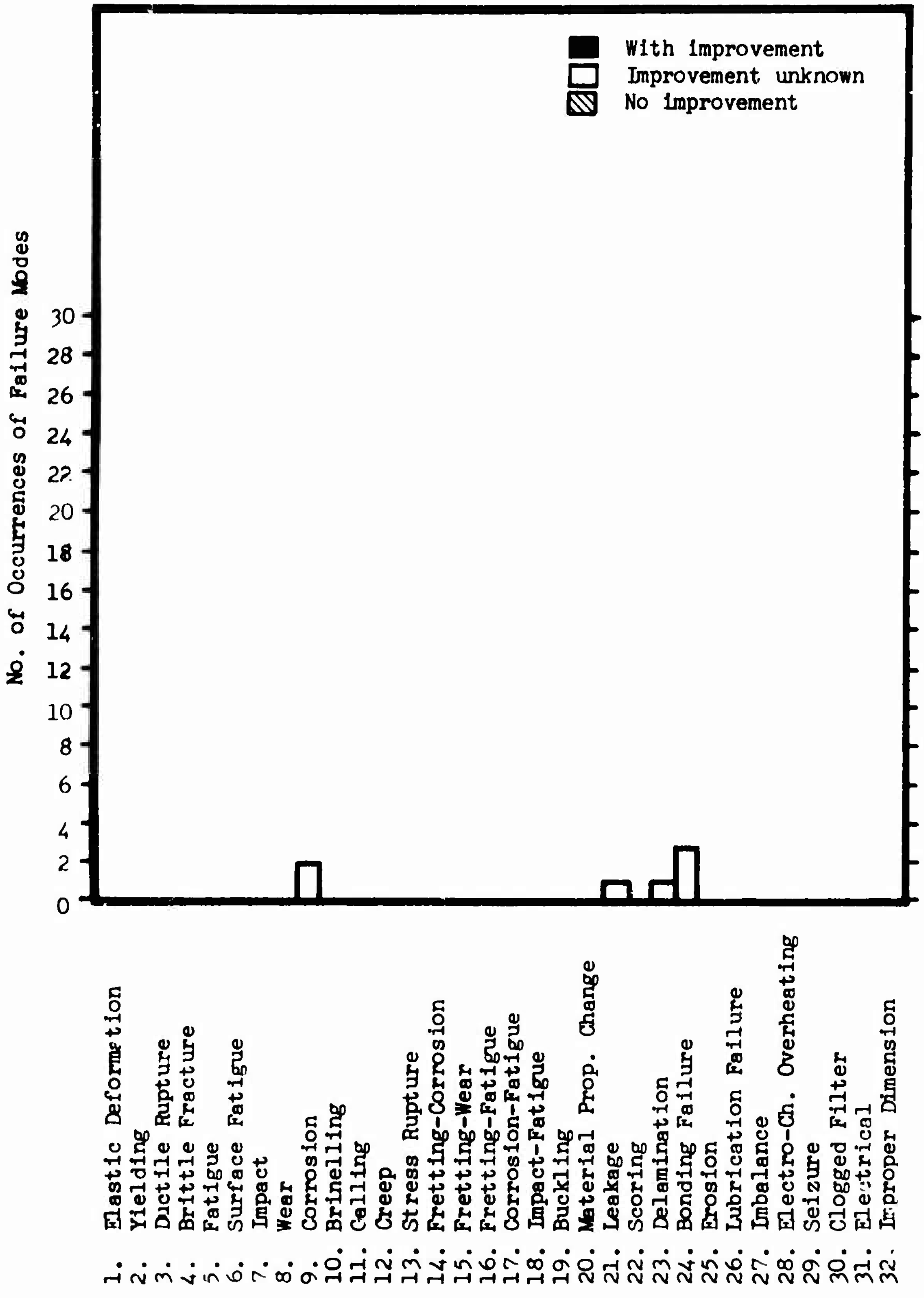

Figure 91. Frequency of Occurrence of Failure Modes for <u>Added Sealant</u> Corrective Action - Series III.

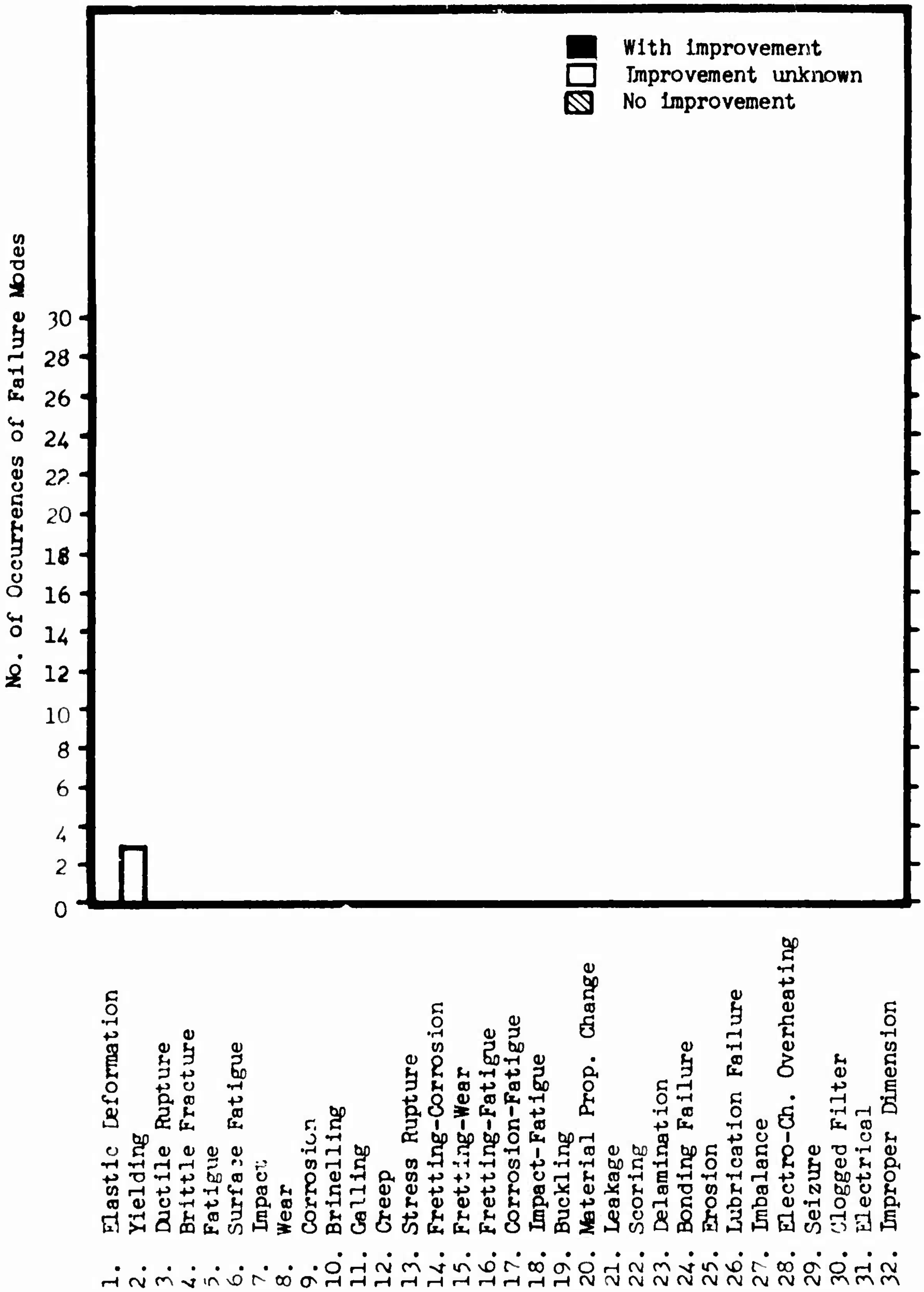

Figure 92. Frequency of Occurrence of Failure Modes for Added or Changed Locking Feature Corrective Action - Series III.

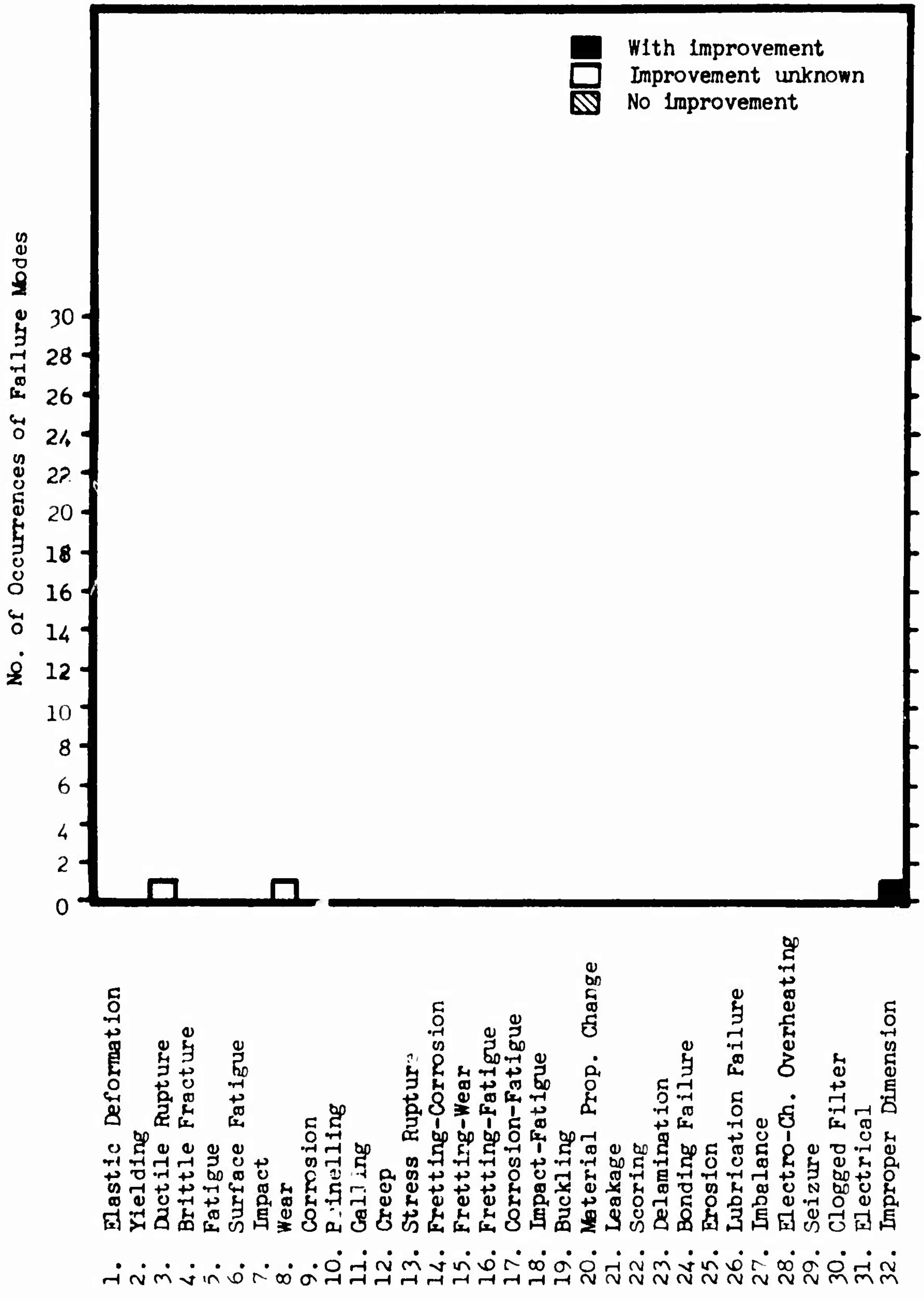

Figure 93. Frequency of Occurrence of Failure Modes for <u>Adjusted Part</u> Corrective Action - Series III.

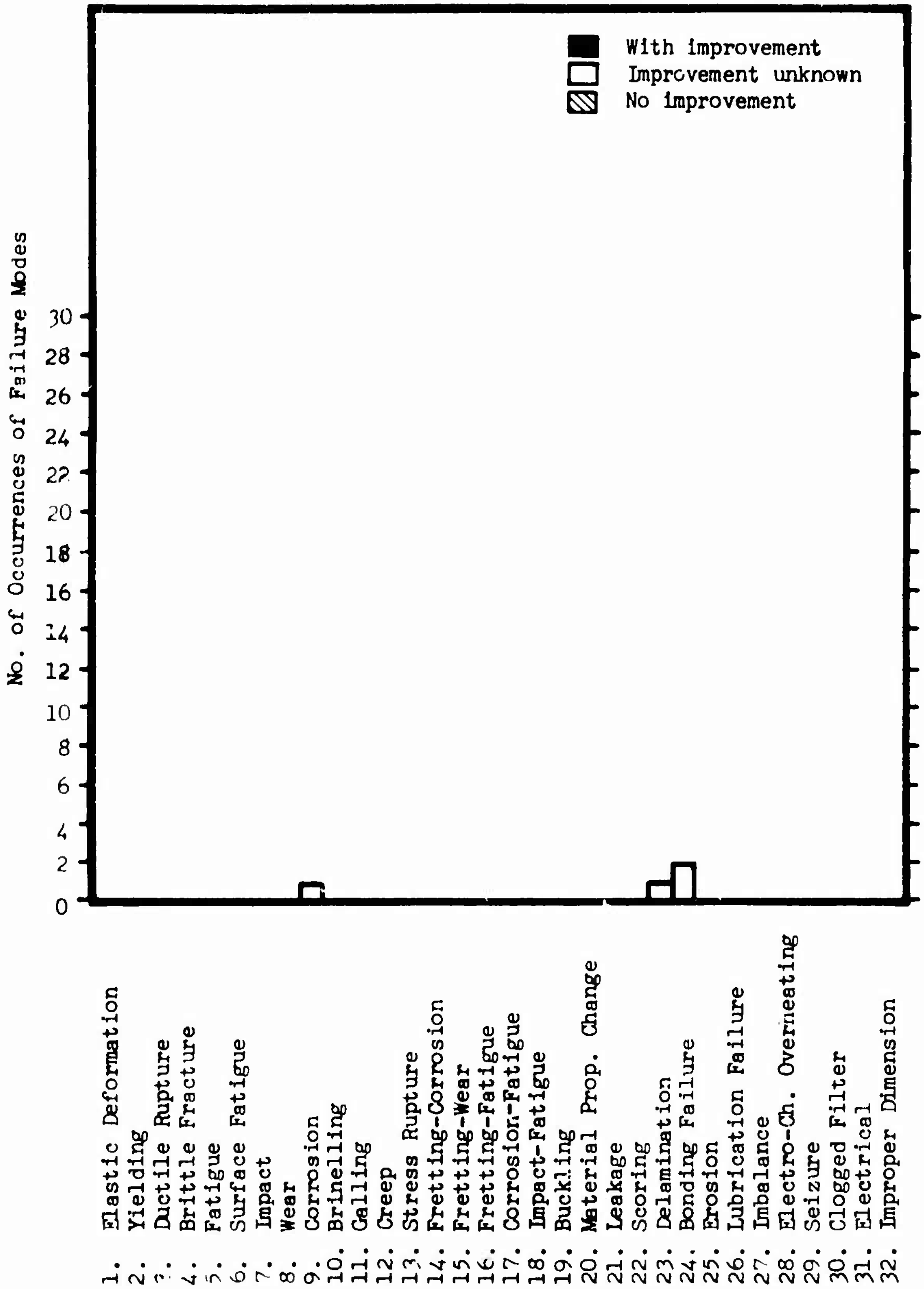

Figure 94. Frequency of Occurrence of Failure Modes for Provided Drain Corrective Action - Series III.

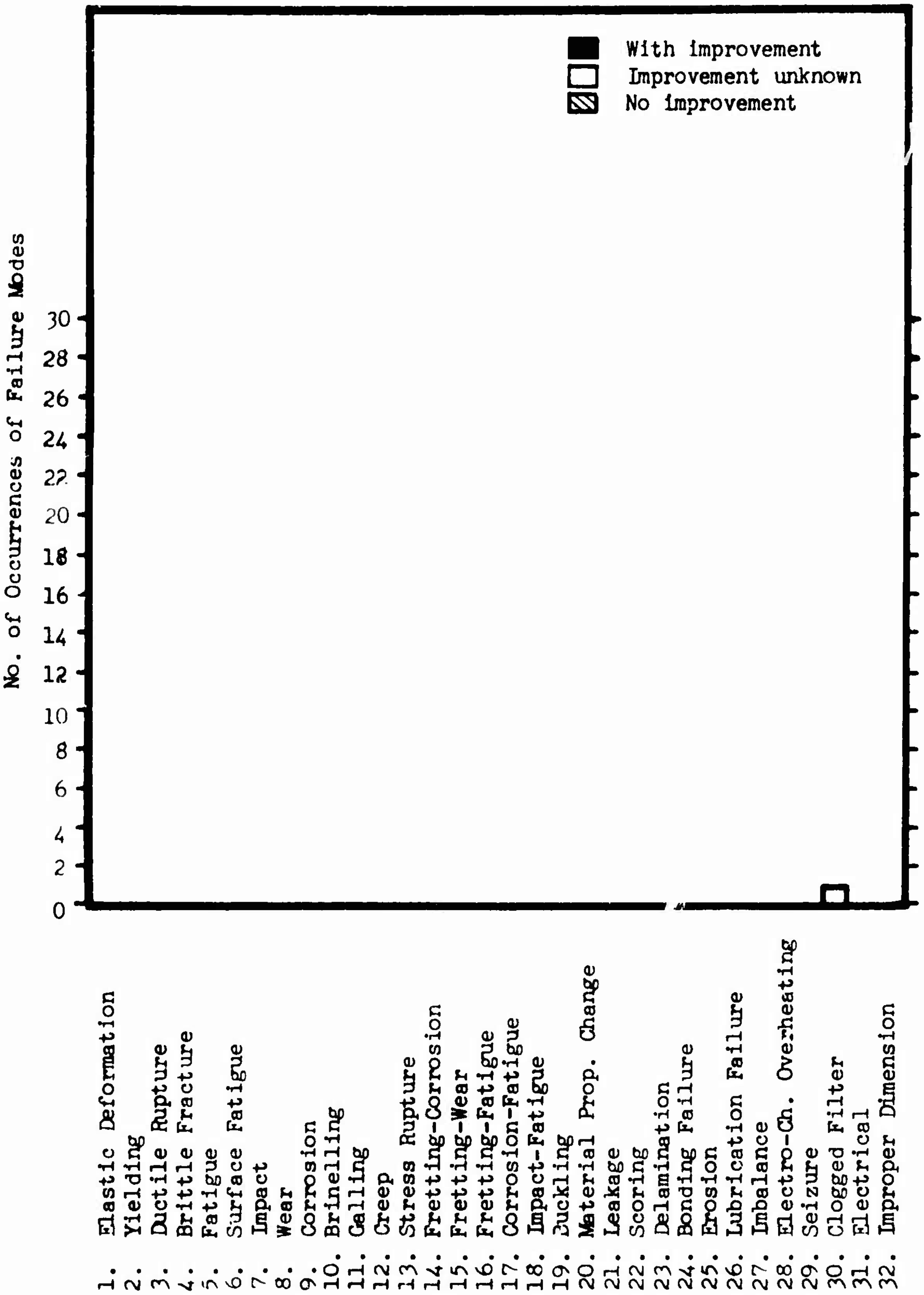

Figure 95. Frequency of Occurrence of Failure Modes for <u>More Easily Replaceable</u> Corrective Action - Series III.

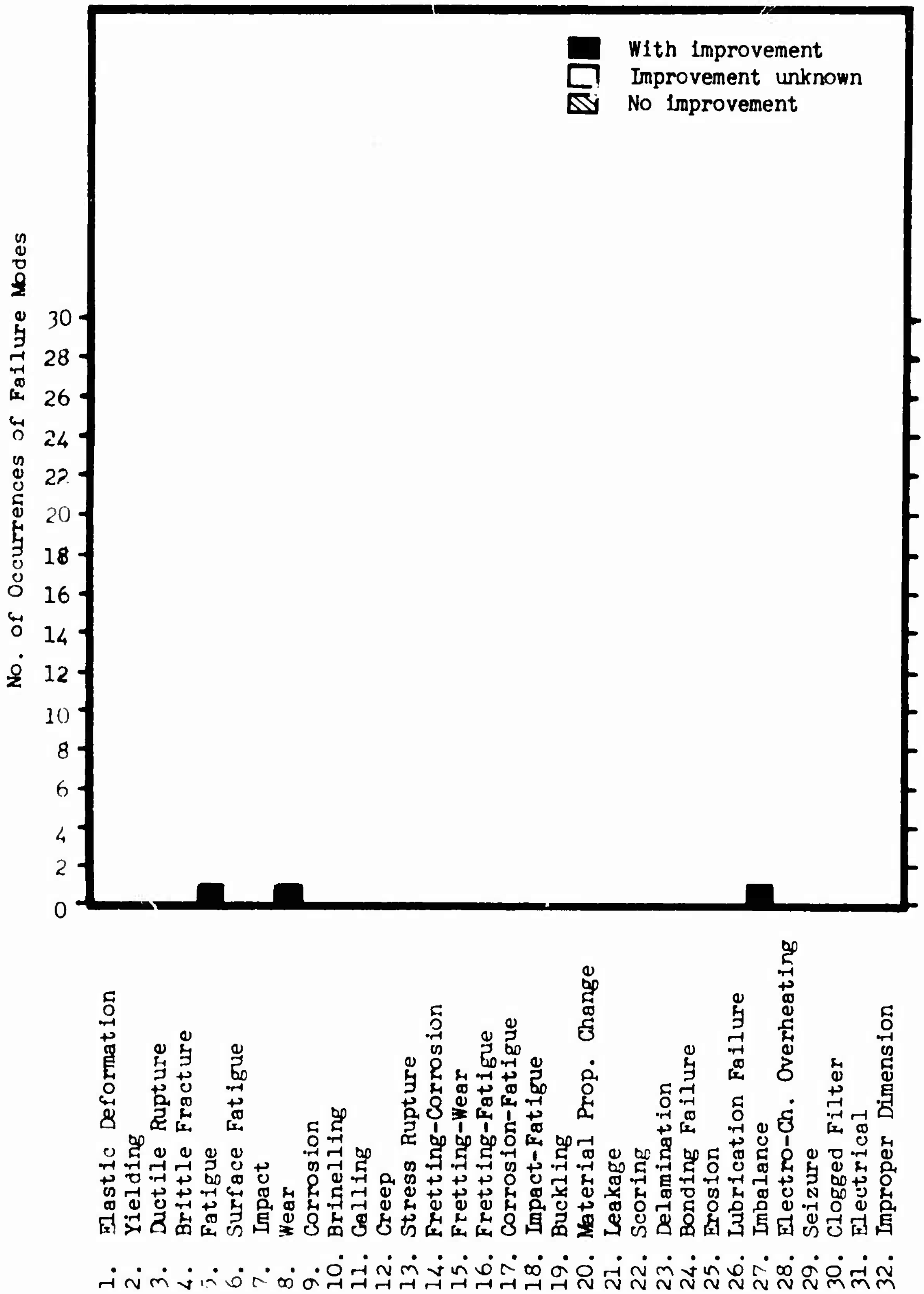

Figure 96. Frequency of Occurrence of Failure Modes for Changed to Correct Part Corrective Action - Series III.

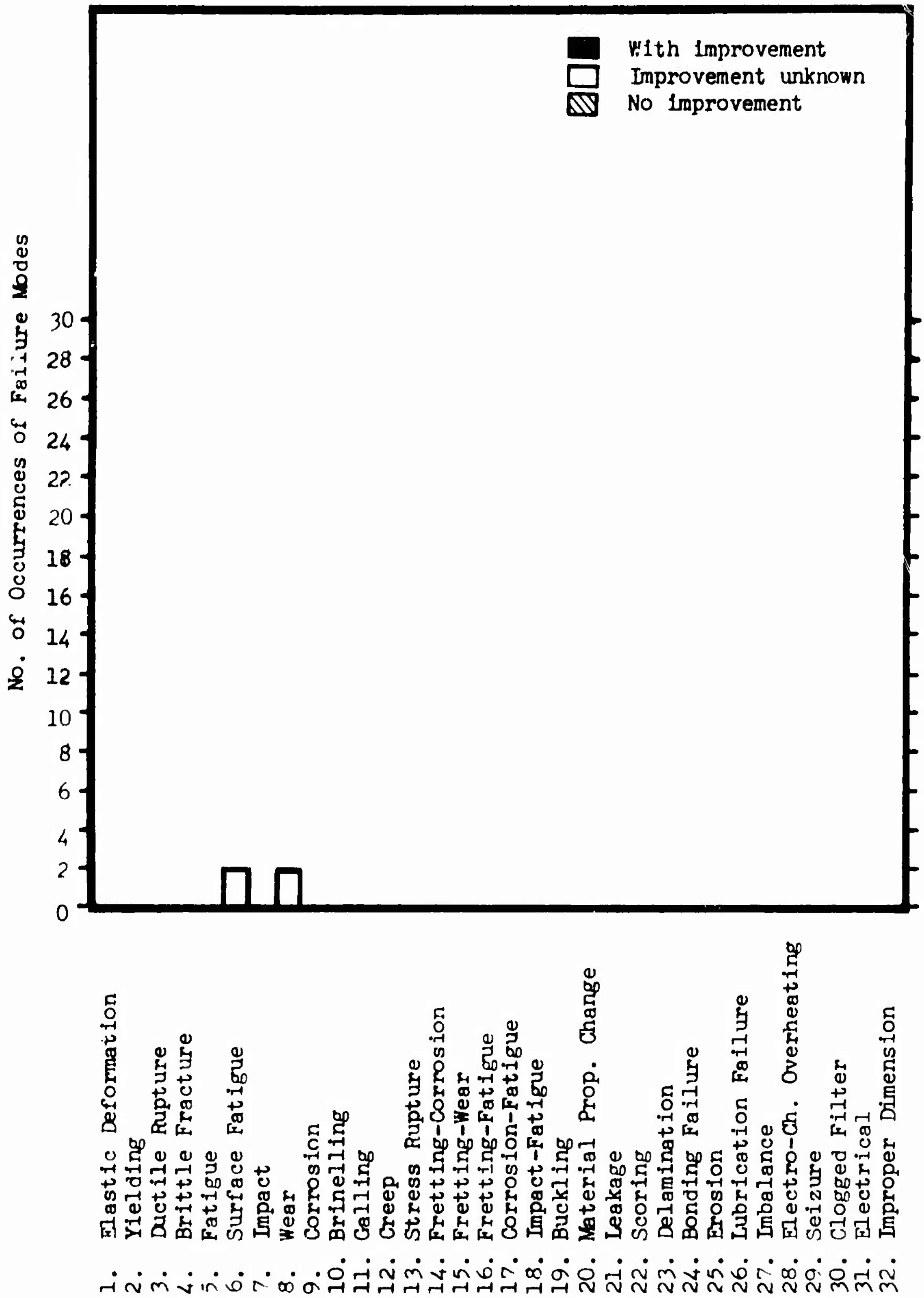

Figure 97. Frequency of Occurrence of Failure Modes for Improved Lubrication Corrective Action - Series III.

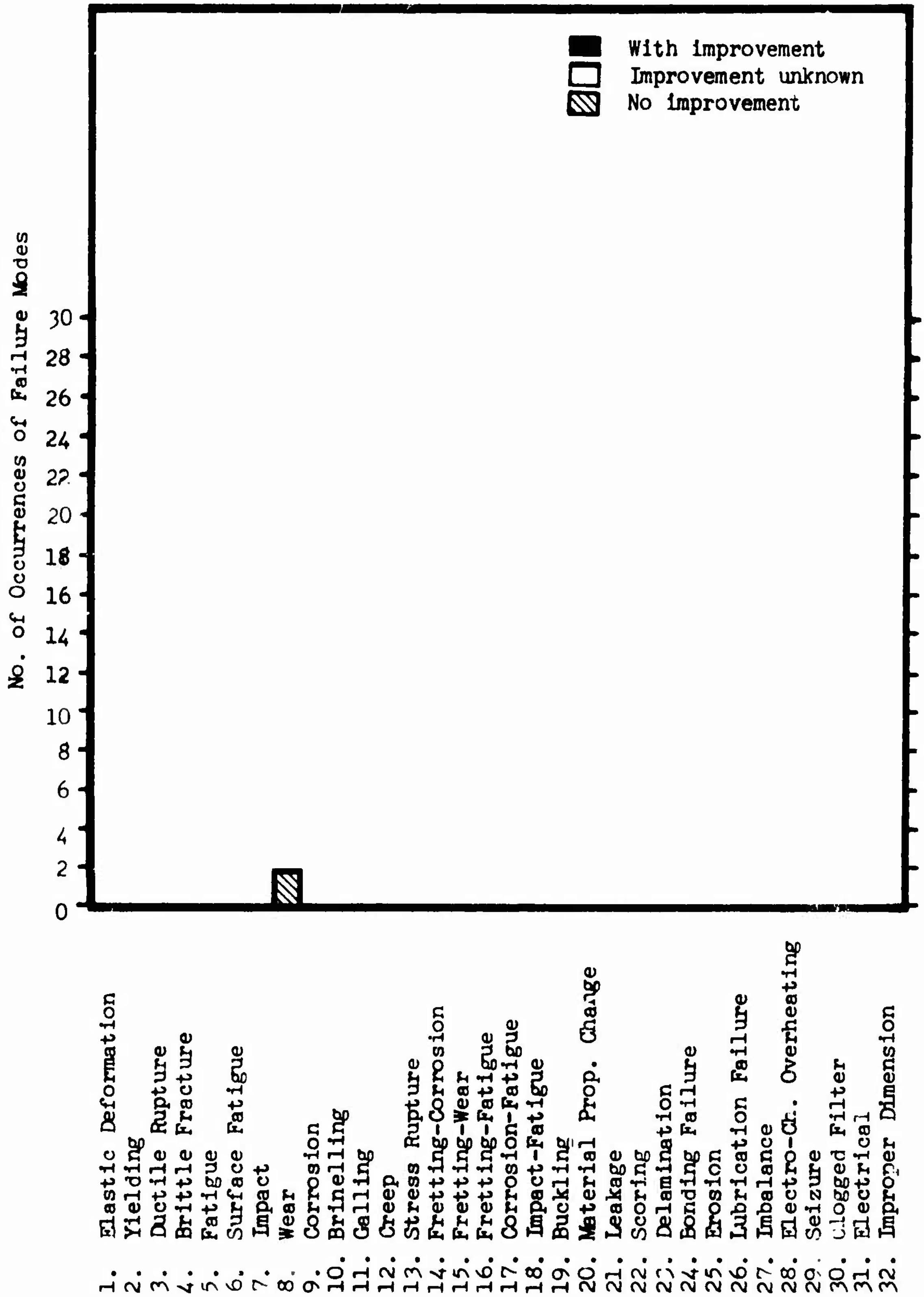

Figure 98. Frequency of Occurrence of Failure Modes for Made Parts Interchangeable Corrective Action - Series III.

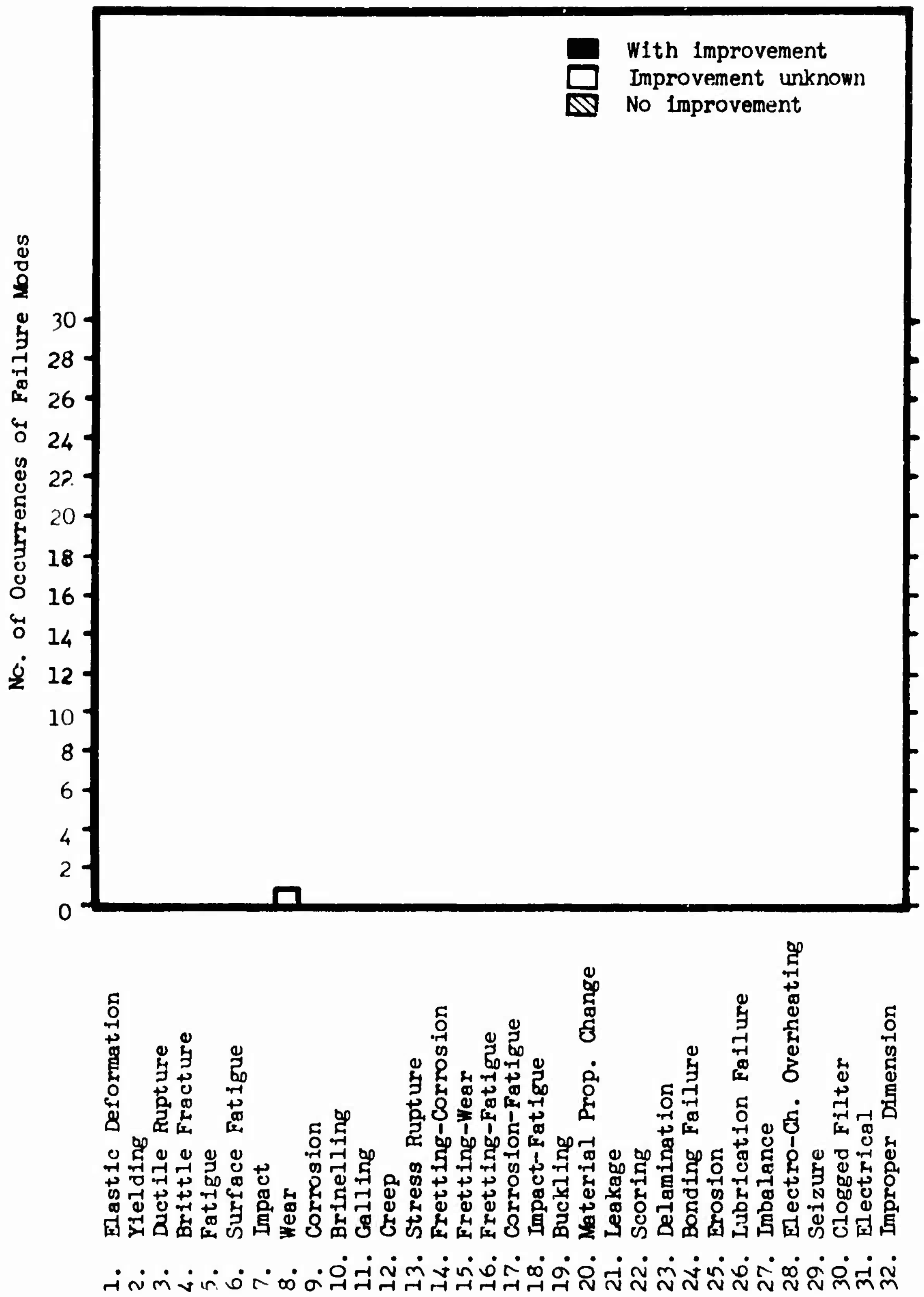

Figure 99. Frequency of Occurrence of Failure Modes for Relaxed Replacement Criteria Corrective Action -Series III.

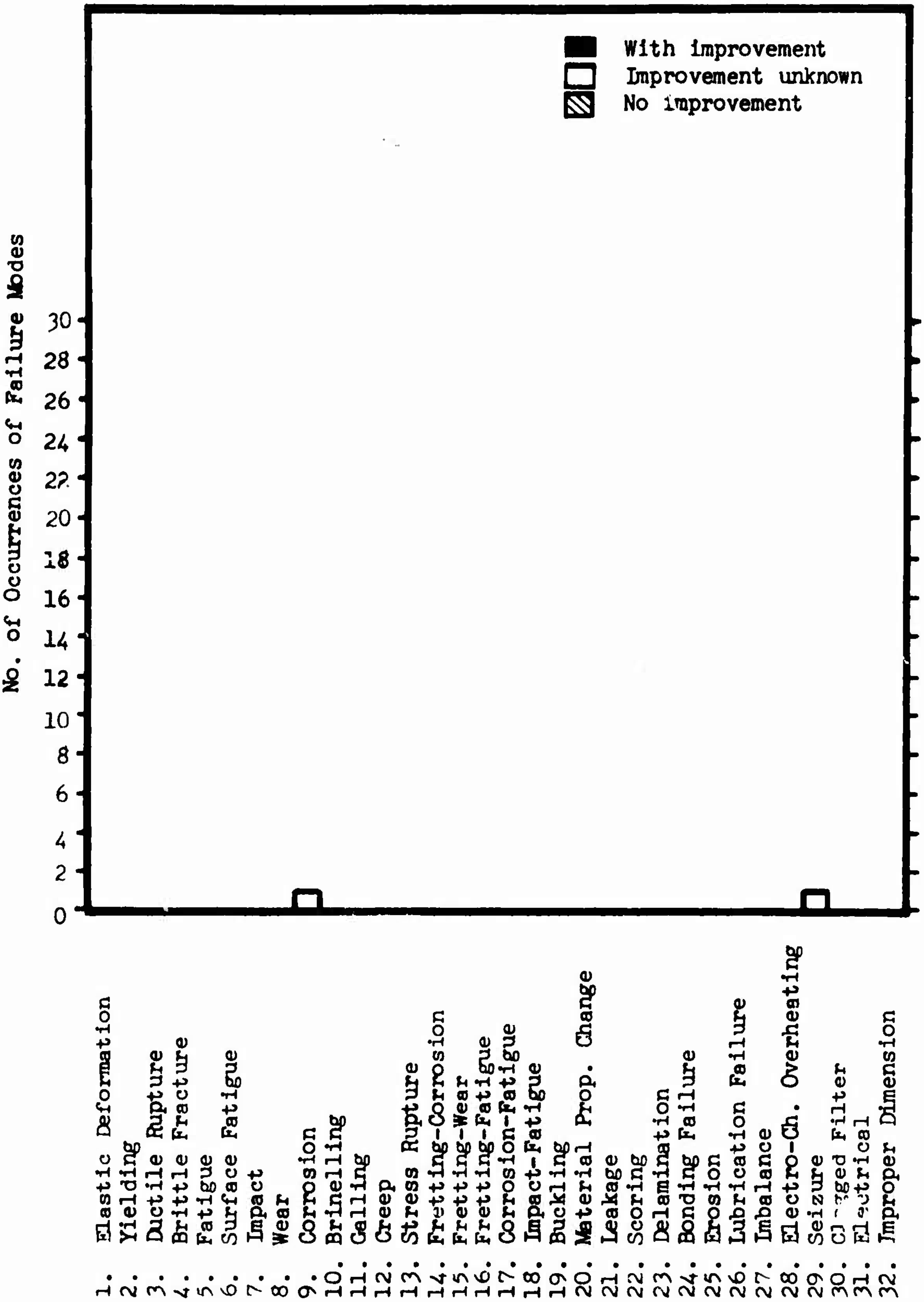

Figure 100. Frequency of Occurrence of Failure Modes for Revised Procurement Specifications Corrective Action-Series III.

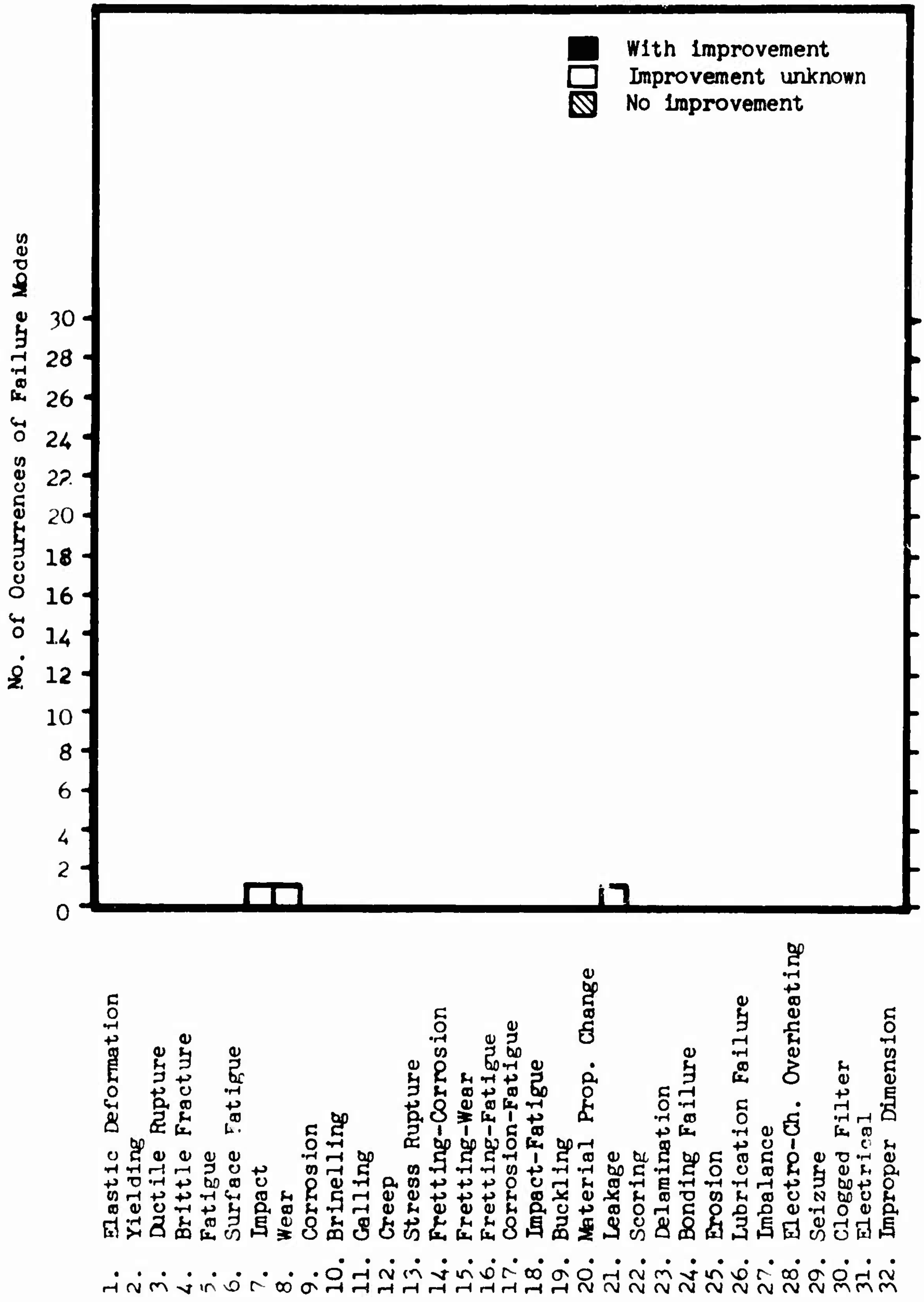

Figure 101. Frequency of Occurrence of Failure Modes for Provided Means for Proper Inspection Corrective Action - Series III.

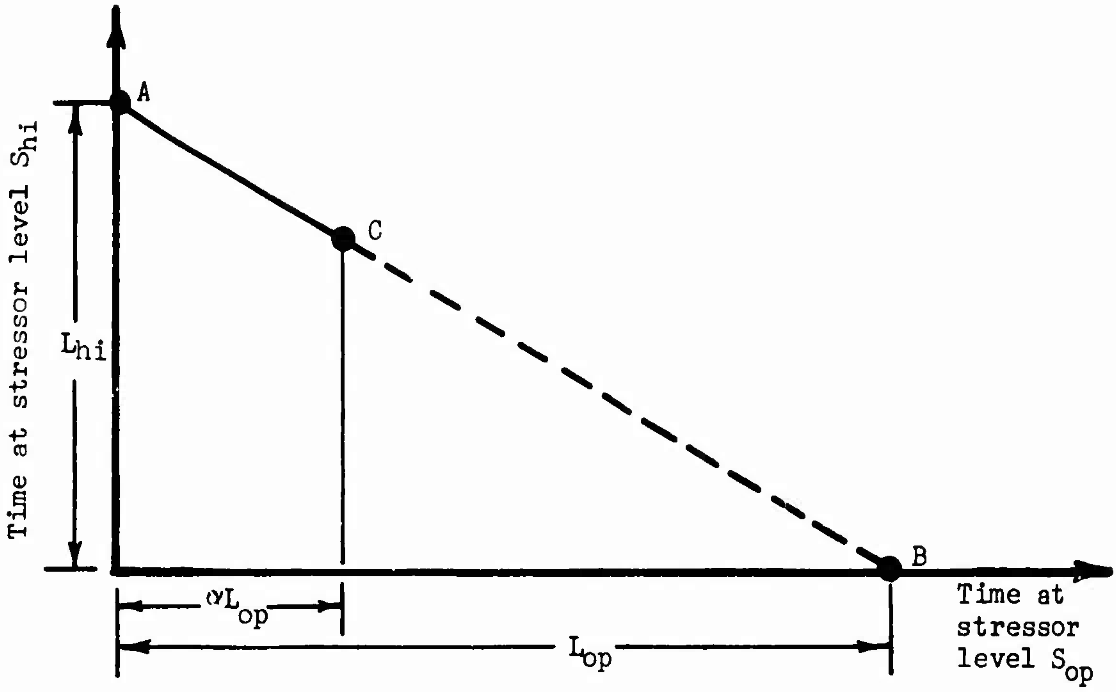

Figure 102. Example of Accelerated Life Testing Using the Linear Cumulative Damage Model.

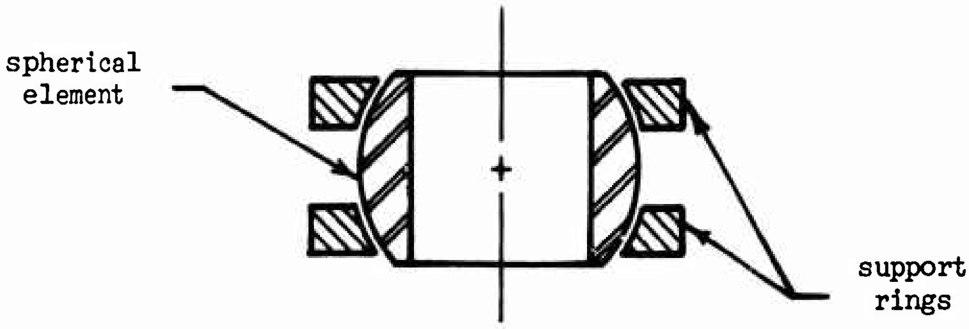

Figure 103. Schematic View of Cyclic Servo Support Bearing.

REFERENCES

1. Clark, M. W., Krauss, W. K., and Ciccotti, J. M., IDENTIFICATION AND ANALYSIS OF ARMY HELICOPTER RELIABILITY AND MAINTAINABILITY PROBLEMS AND DEFICIENCIES, Vols. II, III and IV, American Power Jet, USAAMRDL Technical Reports 72-11B, 72-11C, and 72-11D, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, April, 1972, AD901457L, AD901458L, and AD901459L.

2. OPERATIONS RELIABILITY/MAINTAINABILITY ENGINEERING PROGRAM ACCOMPLISHMENT REPORTS, Report No. SER-64340, Sikorsky Aircraft Division, United Aircraft Corp., Stratford, Connecticut.

3. Bell Helicopter Co., REPORT NO. 205-099-157, Fort Worth, Texas.

4. Burwell, J. T., Jr., SURVEY OF POSSIBLE WEAR MECHANISMS, Wear, Vol. 1, 1957, pp 119-141.

5. Miner, M. A., CUMULATIVE DAMAGE IN FATIGUE, Journal of Applied Mechanics, Vol. 12; Trans. ASME, Vol. 17, June, 1945, pp 159-164.

6. Rabinowicz, E., McEntire, R. H., and Shwalkar, B., A TECHNIQUE FOR ACCELERATED LIFE TESTING, Trans. ASME, August 1970, pp 706-710.

7. Rabinowicz, E., FRICTION AND WEAR OF MATERIALS, New York, John Wiley and Sons, 1966.

8. MacGregor, C. W. (ed), HANDBOOK OF ANALYTICAL DESIGN FOR WEAR, New York, Plenum Press, 1964.

APPENDIX I
GLOSSARY FOR FAILURE MODES

1. Bonding Failure is the inability of an adhesive material to maintain a sound union between two members whose attachment is dependent primarily upon the adhesive material.

2. Brinelling failure occurs when the static forces between two curved surfaces in contact - such as a ball bearing ball and race - result in local yielding of one or both mating members to produce a permanent surface irregularity of significant size. Subsequent operation of a bearing that has brinelled is likely to result in intolerably increased vibration, noise, and heating.

3. Brittle Fracture failure occurs when the elastic deformation, in a machine member which exhibits brittle behavior, is carried to the extreme, whereby the primary interatomic bonds are broken and the member separates into two or more pieces.

4. Buckling failure occurs when, due to a critical combination of magnitude and/or point of load application together with the geometrical configuration of a machine member, the deflection of the member suddenly increases greatly due to only a slight increase in load, thereby rendering the member incapable of performing its function.

5. Change in Material Property failure is recognized as the swelling, softening, drying out, crumbling, or general chemically induced permanent deformation or deterioration of a nonmetallic material.

6. Clogged Filter failure is a failure attributed to a filter element that has trapped an excessive quantity of impurities which block or restrict the normal flow of a fluid.

7. Combined Creep and Fatigue failure is a combination failure mode in which all of the conditions for both creep failure and fatigue failure exist simultaneously, each process influencing the other to produce failure. The interaction of creep and fatigue is probably synergistic but not well understood.

8. Corrosion failure occurs when a machine member is rendered incapable of performing its intended function due to the degradation and deterioration of the material from which the member is made, due to chemical or electrochemical attack.

9. Corrosion-Fatigue failure occurs when both corrosion and fatigue combine their deleterious effects, each process thereby accelerating the other, to cause failure of a machine member.

10. Corrosion-Wear failure is a combination failure mode in which corrosion and wear combine their deleterious effects to incapacitate a machine part. The corrosion process often produces a hard abrasive corrosion product which accelerates the wear, while the wear process constantly removes the protective corrosion layer from the surface, baring fresh metal to the corrosive medium, accelerating the corrosion. The two modes combine to make the result more serious than either of the modes would have been otherwise.

11. Creep failure occurs whenever the plastic deformation in a machine member accrues over a period of time under the influence of stress and temperature until the accumulated dimensional changes interfere with the ability of the machine member to satisfactorily perform its intended function.

12. Creep Buckling failure occurs when after a period of time the creep process results in an unstable combination of the loading and geometry of a machine part so that the critical buckling limit is exceeded and failure ensues.

13. Delamination failure is the separation of layers of composites or multilayered constructions. It is distinguished from bonding failure primarily by the number of surfaces bonded together.

14. Ductile Rupture failure occurs when the plastic deformation, in a machine member which exhibits ductile behavior, is carried to the extreme whereby the member separates into two pieces or exhibits a partial separation.

15. Elastic Deformation failure occurs whenever the elastic (recoverable) deformation in a machine member, brought about by the imposed operational loads or temperatures, becomes great enough to interfere with the ability of the machine to satisfactorily perform its intended function.

16. Electrochemical Overheating failure is excessive heat generation resulting from the interaction of electric current and chemical reactions. In this study, the failure is observed only in storage batteries.

17. Electrical failure is used to designate any failure of an electrical nature that cannot be classified as a mechanical malfunction.

18. Erosion failure is the gradual wearing away of a surface as the result of fluid borne abrasive particles passing over the surface.

19. <u>Fatigue</u> failure is the sudden and catastrophic separation of a machine part into two or more pieces due to the application of fluctuating loads or deformations over a period of time. Failure takes place by the initiation and propagation of a crack until it becomes unstable and suddenly propagates to failure.

20. <u>Fretting-Corrosion</u> failure occurs when a machine part is rendered incapable of reliably performing its function due to the degradation of the material as a result of fretting action, which may take place at the interface between any two solid bodies whenever they are pressed together by a normal force and subjected to small-amplitude cyclic relative motion with respect to each other. Fretting frequently takes place in joints that are not intended to move, but due to vibrational loads or deformations experience minute motions.

21. <u>Fretting-Fatigue</u> failure is the premature, or unexpected, fatigue fracture of a machine member subjected to fluctuating loads or strains together with conditions which simultaneously produce fretting action. The surface discontinuities and microcracks generated by the fretting action act as fatigue crack nuclei which propagate to failure under conditions of fatigue loading which would otherwise be acceptable.

22. <u>Fretting-Wear</u> failure occurs when the changes in dimensions of the mating parts, due to the presence of fretting action, become large enough to interfere with proper design functions, or large enough to produce geometrical stress concentration of such magnitude that failure ensues due to excessive local stress levels.

23. <u>Galling</u> failure occurs when two sliding surfaces are subjected to such a particular combination of loads, sliding velocities, temperatures, environments and lubricants, that massive surface destruction is caused by welding and tearing, plowing, gouging, significant plastic deformation of surface asperities, and metal transfer and smearing between two surfaces.

24. <u>Imbalance</u> failure is the intolerable vibration or rough operation of rotating parts resulting from the improper location of the center-of-mass of the moving parts.

25. <u>Impact</u> failure occurs when a machine member is subjected to nonstatic loads which produce in the part stresses or deformations of such magnitude that the member is broken or deformed beyond use. The failure is brought about by the interaction of stress or strain waves generated by dynamic or suddenly applied loads which induce local stresses and strains many times greater than the static application of the same loads.

26. Impact-Fatigue failure occurs when impact loading is repetitively applied to a machine member until failure occurs by the nucleation and propagation of a fatigue crack.

27. Improper Dimension failure is restricted to those cases where a definite dimension or size of a part is specified but a different one is discovered in use after failure is experienced.

28. Leakage failure is the undesired entrance or escape of a fluid or of small particles that results in malfunction or damage of a system or its components. Leakage is normally the result of other failure modes and is the failure mode specified when more specific details are not known.

29. Lubrication Failure is the breakdown or other inability of a lubricant to properly lubricate moving parts.

30. Radiation Damage failure occurs when the changes in material properties induced by exposure to a nuclear radiation field are of such a type and magnitude that the machine part is no longer able to perform its intended function, usually due to the triggering of some other failure mode.

31. Scoring failure is the scratching, scuffing, or unintentional marking of a surface that is critically affected by much surface blemishes.

32. Seizure failure is the cohering or binding fast of two parts which normally move relative to each other. Seizure is induced through the action of excessive friction, temperature, or pressure.

33. Spalling failure occurs whenever a particle is spontaneously dislodged from the surface of a machine part so as to prevent the proper function of the member. Armor plate fails by spalling, for example, when a striking missle on the exposed side of an armor shield generates a stress wave which propagates across the plate in such a way as to dislodge or spall a secondary missle of lethal potential on the protected side.

34. Stress Corrosion failure occurs when the applied stresses on a machine part in a corrosive environment generate a field of localized surface cracks, usually along grain boundaries, which render the part incapable of performing its function, often due to triggering of some other failure mode.

35. Stress Rupture failure is intimately related to the creep process except that the combination of stress, time and temperature is such that rupture into two parts occurs without the long steady state or secondary creep stage commonly experienced with creep.

36. Surface Fatigue failure, usually associated with rolling surfaces in contact, manifests itself as pitting, cracking and flaking of the contacting surfaces, due to the cyclic Hertz contact stresses which result in maximum values of cyclic shear stresses slightly below the surface.

37. Thermal Relaxation failure occurs when the dimensional changes due to the creep process result in the relaxation of a prestrained or prestressed member until it no longer is able to perform its intended function.

38. Thermal Shock failure occurs when the thermal gradients generated in a machine part are so pronounced that differential thermal strains exceed the ability of the material to sustain them without yielding or fracture.

39. Wear failure, usually associated with sliding surfaces in contact, occurs when the changes in dimensions of the mating parts, due to the gradual removal of material from the contacting parts, become large enough that the parts are no longer able to properly perform their design function.

40. Yielding failure occurs whenever the imposed operational loads or motions cause the plastic (unrecoverable) deformation in a machine member to become great enough to interfere with the ability of the machine to satisfactorily perform its intended function.

APPENDIX II
GLOSSARY FOR ELEMENTAL MECHANICAL FUNCTIONS

1. Absorbing. Intercepting (as sound waves) without echo, recoil or the like; receiving, often accompanied by transforming (energy) into other forms, usually causing a rise in temperature.

2. Amplifying. Enlarging or increasing the magnitude or intensity of a quantity, such as electrical amplifying, force amplifying.

3. Attaching. Connecting or joining together by any means of one thing to another; providing or having the capability for being connected to.

4. Balancing. Adjusting the mass distribution relative to some fixed point or axis, such as distributing the mass of a rotating member about its axis of rotation in order to reduce vibrations when running.

5. Clutching. The combined provision for connecting or disconnecting rotating parts at will while one or both are in motion, such as a member used to engage and disengage two rotating shafts in a drive system.

6. Conducting. Serving as a medium for conveying, guiding, or transmitting (electricity or heat).

7. Constraining. Restricting movement, preventing the occurrence of motion or passage of a substance except in a particular and definite manner, such as motion constraining, liquid constraining, etc.

8. Coupling. Joining or connecting two adjacent parts at the ends by a device or part specifically made for that purpose, such as flexible coupling or rigid coupling.

9. Covering. Concealing, sheltering, or protecting from view, from environmental conditions, or from unwanted entrance into an enclosed region, such as protective cover, removable cover.

10. Damping. Retarding or depressing the motion of a body or the effect of a force when a load is suddenly applied or removed, such as motion damping or simply damping for the reduction of intensity of an impressed load.

11. Deflecting. Changing the direction of a flow of a gas or of particles contained in a fluid.

12. Disconnecting. Separating, detaching, or breaking the attachment between joined components, either automatically or with relative ease and convenience if manually operated.

13. Dissipating. Dispersing, causing to disappear, or releasing heat to the surroundings, usually by conductive or convective action.

14. Distributing. Sharing or spreading out of a quantity, such as force distributing, electrical distributing, etc.

15. Fastening. Holding or fixing in place, restricted in use here to the device used for holding parts together, such as bolts, rivets, latches, etc.

16. Filtering. Removing impurities, especially separating solid particles from a passing fluid, such as fuel filtering, air filtering.

17. Guiding. Controlling the direction of, leading, or directing along a predetermined course, especially by physical constraint, such as by ducts or tracks.

18. Increasing. Becoming greater in value, size, or quantity.

19. Indicating. Showing, pointing out, or giving a sign of the amount or value of a quantity, such as pressure indicating, position indicating, etc. (Also, see sensing.)

20. Insulating. Isolating or restricting the passage of sound, heat, or electrical current.

21. Latching. Holding closed with capability for easy disengagement, especially for doors, covers, and windows.

22. Lighting. Giving off visible light, illuminating, making it possible to see where natural light is not sufficient.

23. Limiting. Restricting or confining to a certain range of values, such as motion limiting, pressure limiting, torque limiting.

24. Linking. Joining or connecting together movable parts by an intermediate member.

25. Maintaining. Keeping in a fixed condition, or continuing to exist without change, such as force maintaining.

26. Partitioning. Separating or dividing into compartments or distinct parts.

27. Pivoting. Moving, turning, or swinging about a point or an axis.

28. Pumping. Forcing a fluid to move to a higher elevation or pressure condition by performing work on the fluid.

29. Reducing. Changing to a lower value or amount, as friction reducing; restricting the magnitude of (motion, electrical current).

30. Reinforcing. Strengthening or making stronger, especially by patching, bracing, or adding new material to an existing part.

31. Restoring. Putting or bringing back into a former place, position, or condition.

32. Rolling. Rotating or moving by turning over and over while in contact with a mating surface, without appreciable sliding.

33. Sealing. Confining, preventing passage or flow of, closing off an opening to stop entrance or escape of a substance.

34. Sensing. Detecting and reacting to changes in the condition or value of a quantity. Sensing elements provide the signal to activate an indicating member, as a thermocouple senses temperature change, and a millivolt meter indicates the change in temperature (from a voltage change).

35. Shielding. Guarding, protecting, or deflecting for safety of personnel and/or of parts.

36. Sliding. Moving along a surface without intermission of contact and without rolling.

37. Spacing. Setting apart, separating, or positioning in a definite manner.

38. Stabilizing. Regulating; resisting change or erratic motion; tending to return to an equilibrium or original position after having been displaced.

39. Storing. Putting aside or accumulating for use when needed, such as liquid storing, energy storing.

40. Streamlining. Special shaping or contouring of a solid body in order to minimize disturbance and resistance to flow of an impinging fluid.

41. Supporting. Carrying a load, maintaining the position of a quantity, preventing the motion of, keeping from collapsing.

42. Switching. Opening and closing or diverting the flow of electricity, gas, or liquid.

43. Transferring. Moving or changing from one position or place to another; transporting.

44. Transforming. Changing the form, condition, or nature of; converting (from one form of energy to another).

45. Transmitting. Causing or allowing the passage of; conveying (force, torque, light, etc.) from one mechanical part to another; sending out (radio signals) by electromagnetic waves.

46. Viewing. Providing or having characteristics which enable visual observation or seeing with the eye.

APPENDIX III
GLOSSARY FOR CORRECTIVE ACTIONS

1. Added or Changed Adhesive Material. The application of additional bonding agent of the same type or the use of a different bonding substance.

2. Added or Changed Locking Feature. The use of a new or modified means of maintaining a part in a fixed position relative to another part.

3. Added Sealant. The application of a sealing agent, often in conjunction with mechanical methods, to minimize leakage of a substance, or to exclude contaminants.

4. Adjusted Part. Any manner in which a component, or portion thereof, may be altered by a relatively minor displacement to provide more satisfactory performance with continued use of the original component.

5. Applied Surface Coating. The use of platings, sprays, coatings, etc., on a surface in order to protect the part from operational or environmental damage.

6. Applied Surface Treatment. The use of chemical, thermal, or mechanical action on surfaces so as to change the characteristics of those surfaces when subjected to operational and environmental damage.

7. Change of Material. The use of a material having a composition or constituents different from that of the original component. The change may involve metallic or nonmetallic materials.

8. Changed to Correct Part. The replacement of an improper part inadvertently used by one designed specifically for such usage.

9. Changed Dimensions. A dimensional modification in a part to improve fit, increase strength, or increase rigidity. The change is usually local and does not usually affect the overall size, shape, or function of the part.

10. Changed Electrical Characteristics. Any one of several alterations in the electrical properties, property values, or components in an electrical circuit intended to provide more trouble-free service or more desirable operating characteristics.

11. Changed Loading on Part. The reduction or redistribution of loads on a member by virtue of changing the operational envelope of the system of which the member is a part.

12. Changed Manufacturing Procedure. Any change in the methods, techniques, and/or operational steps during the manufacturing stage to improve product reliability.

13. Change Mechanism of Operation. The use of a new and different part whose principle of operation differs significantly but accomplishes the same task as the original part.

14. Changed Method of Attachment. The introduction of a new or supplemental means of holding parts together.

15. Changed Method or Frequency of Lubrication. The use of a different kind of lubricant and/or means of applying it, or the revision of the intervals at which fresh lubricant is supplied.

16. Changed Type or Added Lubricant. The use of a different type of oil, a different type of grease, etc., or the addition of lubricant where none had been used previously.

17. Changed Vendor. The selection of a different supplier and/or manufacturer whose component is claimed to meet the same specifications required of the previous vendor's component. The same parts from different manufacturers sometimes have widely different performance characteristics that cannot be readily explained.

18. Direct Replacement. The correction of a failure by removing a damaged part and replacing it with a new part of the same make as the damaged part. The replacement part has not been revised or modified in any way to improve its performance or life.

19. Eliminated Part. The removal from service of a malfunctioning part, extraneous or otherwise, whose physical presence is not absolutely essential for operation of the equipment.

20. Improved Instructions to Field Personnel. The use of Modification Work Orders, Technical Bulletins, or other directives to change and/or improve instructions for installation, maintenance, repair, lubrication, etc., in order to reduce damage and increase life or improve performance.

21. Improved Lubrication. Any manner in which the system, quantity, frequency, kind or type of lubrication may have been changed, but for which the details are unavailable.

22. Improved Part. A general term implying that a change, or a combination of changes, in size, configuration, material, protective coating, tolerances, hardness, etc., were used to effect an improvement in performance, but the specific changes are unknown.

23. Improved Quality Control. Any added checks or tests performed during the manufacturing process to insure that a part better meets the design specifications and limits.

24. Improved Run-In Procedure. The use of new guidelines, based on prior experience, to assure that contacting parts are properly mated together during an initial operating period.

25. Made Parts Interchangeable for Inventory. The design change of components to allow for interchangeability and thereby a reduction in the number of items required in inventory.

26. More Easily Replaceable. The redesign or modification of a part and/or the installation procedures to minimize downtime and expedite maintenance.

27. Provided Drain. The addition of an opening to direct the discharge of water or other liquid and prevent an accumulation or seepage that may result in damage.

28. Provided Means for Proper Inspection. A modification of a component or its surroundings for greater accessibility in observing or assessing the condition or performance of the component.

29. Reinforced Part. The addition of separate members to an existing part so as to improve the structural integrity of that member.

30. Relaxed Replacement Criteria. A revision of the specified conditions or requirements to replace a part to less frequent time periods or to strict requirements on the condition of the part.

31. Relocated or Repositioned Part. These terms are used to indicate that a part has been moved to a more advantageous or safer position either for the part moved or for surrounding parts.

32. Repaired. Any method employed to return a damaged part to a usable condition to avoid the necessity for immediate replacement of the part.

33. Revised Procurement Specifications. The change of requirements stated in the procurement specifications pertaining to acceptance, testing, or other particulars that have not provided the desired product condition.

34. Strengthened Part. Any manner by which the strength of a member is increased, while still retaining the same general overall size, shape, and function. This term is used in those situations where the specific means for obtaining added strength are not known.

35. Supplemental Part. The continued use of the original part, supplemented by a new separate component whose purpose is to assist and/or protect the original member.

APPENDIX IV

BASIC INFORMATION STORED IN FAILURE-EXPERIENCE MATRIX

TABLE XIV. INFORMATION FOR EACH PART CONTAINED IN THE FAILURE-EXPERIENCE MATRIX

Case/Item	Part Name	Helicopter Type/Model/Series
	FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	
1a	Damper FM: Leakage, wear, seizure. FN: Motion damping, energy absorbing, energy dissipating, motion reducing, stabilizing. CA: Improved part (wave washer in damper), UU[1]. Improved instructions to field personnel, UU.	UH-1B, C, D, H
1b	Retaining Clip FM: Fatigue, impact, impact-fatigue. FN: Supporting, attaching. CA: Improved instructions to field personnel, UU.	UH-1B, C, D, H
2a	Windshield FM: Scoring, stress rupture. FN: Protective covering, viewing, shielding, light transmitting. CA: Improved instructions to field personnel (for cleaning and repair), UU. Direct replacement, UNI[2]. Change of material (.090 glass-acrylic laminate), TI[3]. Applied surface coating (scratch-resistant coating), TI.	UH-1A, B, C, D, H
2b	Cabin Roof Window FM: Brittle fracture, stress rupture. FN: Protective covering, viewing, shielding, light transmitting. CA: Improved instructions to field personnel (for cleaning and repair), UU.	UH-1A, B, C, D, H
3a	Latch FM: Ductile rupture. FN: Latching, motion constraining. CA: Improved part (replaced crew doors UH-1A), UU.	UH-1A, B, C, D, H

TABLE XIV - Continued	
Case/Item	**Part Name** — **Helicopter Type/Model/Series** **FM: Failure Mode(s)** **FN: Function(s)** **CA: Corrective Action(s)**
3b	Door Race — UH-1A,B,C,D,H FM: Ductile rupture, impact. FN: Guiding, motion constraining, supporting. CA: Repaired part, UNI.
3c	Nylon Roller — UH-1A,B,C,D,H FM: Wear, ductile rupture, surface fatigue. FN: Rolling, motion constraining, supporting, friction reducing, attaching. CA: Changed mechanism of operation (roller to slider), UI[4].
3d	Track — UH-1A,B,C,D,H FM: Wear, galling, fatigue. FN: Guiding, motion constraining, supporting. CA: Change of material (stainless steel inserts D/H models), UU.
3e	Handle — UH-1A,B,C,D,H FM: Ductile rupture. FN: Force transmitting, force amplifying. CA: Improved part (replaced crew doors UH-1A), UU.
3f	Door Post Corners — UH-1A,B,C,D,H FM: Impact, yielding, fatigue, ductile rupture. FN: Supporting. CA: Repaired part, UNI.
3g	Windows — UH-1A,B,C,D,H FM: Impact. FN: Protective covering, viewing, shielding, light transmitting. CA: Direct replacement, UNI.
3h	Hinges — UH-1A,B,C,D,H FM: Yielding, impact, wear, ductile rupture. FN: Pivoting, supporting, motion constraining, limiting, attaching. CA: Improved part (replaced crew doors UH-1A), UU.

TABLE XIV - Continued

Case/Item	Part Name / FM: Failure Mode(s) / FN: Function(s) / CA: Corrective Action(s)	Helicopter Type/Model/Series
3i	Door Stop FM: Impact, wear, ductile rupture. FN: Motion limiting. CA: Improved part, UU.	UH-1A,B,C,D,H
3j	Door Slider FM: Wear. FN: Sliding, supporting, motion constraining, friction reducing, attaching. CA: Repositioned part (inverted slider to wear other side), UNI. Supplemental part (added cargo door brackets), UU. Supplemental part (added retaining strap: cargo doors), UU.	UH-1A,B,C,D,H
4a	Engine Deck FM: Bonding failure, corrosion, fatigue, ductile rupture, yielding. FN: Supporting, protective covering. CA: Improved instructions to field personnel (repair of bond voids), UU. Repaired part, UNI. Changed manufacturing procedure (cleaning treatment of titanium), UU.	UH-1A,B,C,D,H
4b	Transmission Deck FM: Bonding failure, corrosion, fatigue, ductile rupture, yielding. FN: Supporting, protective covering. CA: Improved instructions to field personnel (repair of bond voids), UU. Changed manufacturing procedure (cleaning treatment of titanium), UU.	UH-1A,B,C,D,H
4c	Work Decks FM: Bonding failure, corrosion, fatigue, ductile rupture, yielding, impact. FN: Supporting, protective covering. CA: Changed dimensions (skin thickness increased, .012 to .025 Al.), UU. Improved instructions to field personnel (repair of bond voids), UU. Repaired part, UNI. Changed manufacturing procedure (cleaning treatment of titanium), UU. Improved quality control (testing and acceptance criteria), UU.	UH-1A,B,C,D,H

TABLE XIV - Continued	
Case/Item	**Part Name** — **Helicopter Type/Model/Series** **FM: Failure Mode(s)** **FN: Function(s)** **CA: Corrective Action(s)**
4d	Bulkhead — UH-1A,B,C,D,H FM: Bonding failure, corrosion, fatigue, ductile rupture, yielding. FN: Supporting, partitioning. CA: Improved instructions to field personnel (repair of bond voids), UU. Repaired part, UNI. Changed manufacturing procedure (cleaning treatment of titanium), UU.
4e	Fuel Cell Panels — UH-1A,B,C,D,H FM: Bonding failure, corrosion, fatigue, ductile rupture, yielding. FN: Supporting, partitioning, protective covering. CA: Improved instructions to field personnel (repair of bond voids), UU. Repaired part, UNI. Changed manufacturing procedure (cleaning treatment of titanium), UU.
5a	Tail Boom Fittings — UH-1B,D,H FM: Ductile rupture. FN: Supporting, force transmitting, attaching. CA: Direct replacement (upper L.H. fitting), UNI. Supplemental part (tail boom stiffener installed), UU. Improved part (boom attachment bolts improved), UU.
5b	Longeron Supporting Battery Shelf — UH-1B,D,H FM: Fretting-fatigue, fatigue. FN: Supporting. CA: Improved part (upper L.H. tail boom longeron), UU. Improved instructions to field personnel (inspection of battery shelf/longeron), UU. Improved part (modified aft battery shelf), UU.
5c	Fittings and Spacer Plates — UH-1B,D,H FM: Fatigue. FN: Supporting, force transmitting. CA: Strengthened associated parts, UU.
5d	Bulkhead — UH-1B,D,H FM: Fatigue.

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
5d (cont'd)	FN: Supporting, reinforcing. CA: Strengthened associated parts, UU.	
6a	Camlock (Half-Grommet) Fasteners FM: Yielding, ductile rupture, wear, fretting-wear, fatigue, fretting-fatigue. FN: Removable fastening, attaching. CA: Changed method of attachment (half to full grommets), UU. Eliminated part (air inlet screen), UU. Supplemental part (added particle separator), UU. Changed method of attachment (remove turnlock fasteners), R[5]. Improved associated part (particle separator with peripheral screen), UU.	UH-1A,B,C,D,H
6b	Dzus (Full-Grommet) Fasteners FM: Yielding, ductile rupture, wear, fretting-wear, fatigue, fretting-fatigue. FN: Removable fastening, attaching. CA: Direct replacement, UNI. Eliminated part (air inlet screen), UU. Supplemental part (added particle separator), UU. Changed method of attachment (remove turnlock fasteners), R. Improved associated part (particle separator with peripheral screen) UU.	UH-1A,B,C,D,H
7	Main Rotor Blades FM: Impact, erosion, imbalance, ductile rupture, yielding, corrosion, delamination, bonding failure, fatigue. FN: Aerodynamic force transmitting, supporting, energy transforming. CA: Improved instructions to field personnel, UU. Improved part (modified ballast retention), UU. Improved part (modified blade), UU. Changed dimensions (stiffer trailing edge), UU. Change of material (stainless steel to cobalt abrasive strip), UU. Direct replacement, UNI. Repaired part, UNI. Improved part (tip cap), UU.	UH-1A,B,C,D,H

TABLE XIV - Continued	
Case/Item	Part Name — Helicopter Type/Model/Series FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)
8a	Main Rotor Hub Radius-Ring — UH-1B,D,H FM: Wear, scoring. FN: Shielding, sealing, sliding. CA: Applied surface coating (flame plating of tungsten carbide)UI. Supplemental part (seals, dust shields),UU. Improved instructions to field personnel (cleaning main rotor grip seal area),UU.
8b	Dust Seal — UH-1B,D,H FM: Bonding failure. FN: Sealing, contaminant constraining. CA: Improved part (new seal in supply system),UU. Supplemental part (seals, dust shields)UU. Improved instructions to field personnel (cleaning main rotor grip seal area),UU. Direct replacement, UNI.
8c	Grip Butt-Plate — UH-1B,D,H FM: Leakage, bonding failure. FN: Sealing, covering. CA: Supplemental part (added sealant, adhesive, 2 rivets). Added sealant. Added adhesive.
8d	Channel Seal — UH-1B,D,H FM: Wear. FN: Sealing, liquid constraining. CA: Change of material (filled plastic instead of PTFE),UNI.
9a	Stabilizer Bar Tube — UH-1B,C,D,H FM: Corrosion, ductile rupture, fatigue, corrosion-fatigue. FN: Force transmitting, supporting, stabilizing. CA: Applied surface coating (paste or paint),UI.
9b	Tie-Rod Assembly — UH-1B,C,D,H FM: Ductile rupture, fatigue. FN: Limiting, supporting. CA: Changed mechanism of operation (tube to stainless steel cable),UI. Improved associated part (stat-O-seals at cable inboard attaching bolt),UI.

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
10a	Main Drive Shaft FM: Fatigue, wear, lubrication failure, leakage. FN: Torque transmitting, power transmitting. CA: Changed lubricant type, UU. Supplemental part (elastomeric boot assembly), UU.	UH-1B,C,D,H
10b	Coupling FM: Wear, lubrication failure, leakage. FN: Coupling, torque transmitting, sliding, motion transmitting, motion constraining. CA: Supplemental part (elastomeric boot assembly), UU. Improved part, UU.	UH-1B,C,D,H
10c	O-Ring FM: Ductile rupture, elastic deformation. FN: Sealing, liquid constraining. CA: Supplemental part (elastomeric boot assembly), UU.	UH-1B,C,D,H
11a	Swashplate Inner-Ring Horn FM: Ductile rupture, fatigue, impact-fatigue. FN: Force transmitting, linking, supporting. CA: Applied surface coating (Pennsalt 2473A), UU. Supplemental part (added plates to horns), UU.	UH-1A,B,C,D,H
11b	Washers FM: Yielding. FN: Force distributing. CA: Change of material (washer st. to SAE 1095 or 4340), UU. Changed dimensions (smaller od, thickness), UU.	UH-1A,B,C,D,H
11c	Gimbal-to-Swashplate Bolt FM: Fretting-corrosion. FN: Removable fastening, supporting. CA: Direct replacement, UNI. Added adhesive (Loctite CV4-10), UU.	UH-1A,B,C,D,H
11d	Trunnion Bearing FM: Wear, lubrication failure, fretting-corrosion, corrosion. FN: Force transmitting, motion constraining, friction	UH-1A,B,C,D,H

TABLE XIV - Continued

Case/Item	Part Name / FM: Failure Mode(s) / FN: Function(s) / CA: Corrective Action(s)	Helicopter Type/Model/Series
11d (cont'd)	reducing, linking, supporting, oscillatory rolling, pivoting. CA: Changed frequency of lubrication (50 hr to 25 hr intervals),UU. Changed mechanism of operation (of bearing),UU.	
11e	Uniball Bearing FM: Wear. FN: Force transmitting, motion constraining, friction reducing, supporting, oscillatory sliding, pivoting. CA: Adjusted part (shim, retorqued),UU.	UH-1A,B,C,D,H
11f	Lateral Horn Clevis FM: Wear, scoring, galling. FN: Force transmitting, linking, supporting, attaching. CA: Changed dimensions (of bushing sleeve flange),UU. Improved part (rotating control system),UU.	UH-1A,B,C,D,H
13a	Seal FM: Wear, leakage, ductile rupture. FN: Sealing, liquid constraining. CA: Improved part (quill assy),UU. Improved part (seal),UI.	UH-1 (All Models)
13b	Quill Race FM: Wear. FN: Torque transmitting, power transmitting, clutching, sealing, sliding. CA: Improved part (quill assy),UU.	UH-1 (All Models)
13c	Corrective Sleeve FM: Bonding failure. FN: Sealing, protective covering. CA: Improved part (quill assy),UU. Supplemental part (added wear sleeve),UI.	UH-1 (All Models)
14a	Shims FM: Wear. FN: Spacing. CA: Direct replacement,UNI. Changed to correct part (brass to stainless steel),UI.	UH-1A,B,D,H

TABLE XIV - Continued	
Case/Item	**Part Name** — **Helicopter Type/Model/Series** **FM: Failure Mode(s)** **FN: Function(s)** **CA: Corrective Action(s)**
14b	Ball Bearing — UH-1A,B,D,H FM: Wear, improper dimension (diameter), impact. FN: Oscillatory rolling, supporting, friction reducing, motion constraining, pivoting. CA: Direct replacement (economics), UNI. Improved part. Changed manufacturing procedure (staked), UU. Improved quality control, UU.
14c	Bearing Sleeve — UH-1A,B,D,H FM: Wear, improper dimension (diameter). FN: Supporting, attaching. CA: Changed manufacturing procedure (staked), UU. Improved quality control, UU.
15a	Ball Bearing — UH-1B,C,D,H FM: Wear, impact. FN: Oscillatory rolling, supporting, friction reducing, motion constraining, pivoting, force transmitting. CA: Supplemental part (steel sleeve), UU. Improved part (scissors and sleeve assembly), UU. Repositioned associated part (bolt, hardware), UU.
15b	Lever (Bore of) — UH-1B,C,D,H FM: Wear. FN: Supporting, attaching. CA: Direct replacement, UNI.
15c	Drive-Link Lower Bearing — UH-1B,C,D,H FM: Wear. FN: Oscillatory sliding, supporting, force transmitting, motion constraining, friction reducing, pivoting. CA: Changed vendor, UU. Improved part (scissors and sleeve assembly), UU. Repositioned associated part (bolt, hardware), UU.
15d	Bearing Assembly — UH-1B,C,D,H FM: Bonding failure. FN: Oscillatory sliding, supporting, force transmitting, motion constraining, friction reducing, pivoting.

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
15d (cont'd)	CA: Improved part (scissors and sleeve assembly), UU. Supplemental part (shear bolt), UU.	
15e	Plain Bearing FM: Wear, seizure. FN: Oscillatory sliding, supporting, force transmitting, motion constraining, friction reducing, pivoting. CA: Improved part (scissors and sleeve assembly), UU. Repositioned associated part (bolt, hardware), UU. Supplemental part (sleeve for bearing), UU.	UH-1B,C,D,H
15f	Sleeve Bushing FM: Wear. FN: Spacing, oscillatory sliding, motion constraining, friction reducing. CA: Change of material (aluminum to steel), UNI.	UH-1B,C,D,H
15g	Roller Bearing FM: Wear. FN: Oscillatory rolling, supporting, friction reducing, motion constraining, pivoting, force transmitting. CA: Direct replacement, UNI.	UH-1B,C,D,H
15h	Mast FM: Scoring. FN: Torque transmitting, supporting, attaching, power transmitting. CA: Improved associated part (bushing sleeve for F), UU.	UH-1B,C,D,H
15i	Bearing Set FM: Wear. FN: Oscillatory rolling, supporting, friction reducing, motion constraining, pivoting, force transmitting. CA: Improved part (scissors and sleeve assembly), UU. Repositioned associated part (bolt, hardware), UU.	UH-1B,C,D,H

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
15j	Roller Bearing FM: Wear. FN: Oscillatory rolling, supporting, friction reducing, motion constraining, pivoting, force transmitting. CA: Improved part (scissors and sleeve assembly),UU. Repositioned associated parts (bolt, hardware),UU.	UH-1B,C,D,H
15k	Bearing Set FM: Wear. FN: Continuous rolling, supporting, friction reducing, motion constraining, force transmitting. CA: Direct replacement,UNI.	UH-1B,C,D,H
16b	Antitorque Servo Cylinder FM: Leakage. FN: Pressure supporting, force transmitting, force amplifying. CA: Improved part (hydraulic components),UNI. Change of material,UNI.	UH-1 (All Models)
16c	Cyclic Flight-Control Servo Cylinder FM: Leakage FN: Pressure supporting, force transmitting, force amplifying. CA: Improved part (hydraulic components),UNI. Change of material,UNI.	UH-1 (All Models)
16d	Hoses FM: Ductile rupture, leakage, wear. FN: Liquid transferring, pressure supporting, liquid constraining. CA: Improved part (hydraulic components),UNI. Change of material,UNI.	UH-1 (All Models)
16e	Tubes FM: Ductile rupture, leakage, wear. FN: Liquid transferring, pressure supporting, liquid constraining. CA: Improved part (hydraulic components),UNI. Change of material,UNI.	UH-1 (All Models)

TABLE XIV - Continued	
Case/Item	**Part Name** / **FM: Failure Mode(s)** / **FN: Function(s)** / **CA: Corrective Action(s)** — **Helicopter Type/Model/Series**
16f	Seals — UH-1 (All Models) FM: Leakage. FN: Sealing, liquid constraining, pressure supporting. CA: Improved part (hydraulic components),UNI. Change of material,UNI.
16g	Connections — UH-1 (All Models) FM: Ductile rupture, leakage, fatigue. FN: Attaching, supporting, sealing. CA: Improved part (hydraulic components),UNI. Change of material,UNI.
17a	Attitude Indicator — UH-1B,C,D,H FM: Unknown. FN: Information transmitting, information indicating. CA: Improved part,UU.
17b	Airspeed Indicator — UH-1B,C,D,H FM: Unknown. FN: Information transmitting, information indicating. CA: Direct replacement,UNI.
17c	Radio Magnetic Indicator — UH-1B,C,D,H FM: Unknown. FN: Information transmitting, information indicating. CA: Improved part,UU.
18	Light Bulbs — UH-1 (All Models) FM: Fatigue, impact. FN: Lighting, energy transforming. CA: Improved part,UNI. Supplemental part (isolation shock mount),TIN[6]. Changed loading on part (increased shock resistance),TIN.
19a	Pylon Damper — AH-1G FM: Seizure, impact. FN: Motion damping, energy absorbing, energy dissipating, motion reducing, stabilizing. CA: Improved instructions to field personnel (inspection procedures),UU. Provided repair kit (shims and seals),UNI.

TABLE XIV - Continued	
Case/Item	**Part Name** — **Helicopter Type/Model/Series** **FM: Failure Mode(s)** **FN: Function(s)** **CA: Corrective Action(s)**
19b	Snap Rings — AH-1G FM: Impact, yielding. FN: Limiting, supporting, motion constraining. CA: Relocated associated part (shim), UU.
19c	Lower Rivets — AH-1G FM: Impact, ductile rupture. FN: Permanent fastening, supporting. CA: Changed dimensions (oversize rivets), UU.
19d	Shaft Seal — AH-1G FM: Leakage, change of material properties. FN: Sealing, liquid constraining. CA: Provided repair kit (shims and seals), UNI. Direct replacement, UNI.
19e	Part Containing Rivet Holes — AH-1G FM: Yielding. FN: Permanent fastening, supporting, attaching. CA: Repaired part (repair oversize rivet holes), UNI.
20a	Actuator Gearbox — AH-1G FM: Unknown. FN: Torque transmitting, supporting. CA: Added sealant, UNI.
20b	Air Inlet Filter — AH-1G FM: Clogged filter. FN: Filtering, contaminant reducing. CA: Repaired part, UNI.
21	Canopy Center Window Panel — AH-1G FM: Creep. FN: Protective covering, viewing, shielding, light transmitting. CA: Improved instructions to field personnel (for rigging rain removal nozzle), UU. Changed dimensions of associated part (nozzle), UU. Supplemental part (asbestos heat shield), UU.

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
22a	Plastic Rub-Strip FM: Bonding failure. FN: Sealing, protective covering. CA: Changed dimensions (2 rub strips in place of one), UU. Changed method of attachment (rivets to screws), UU. Improved instructions to field personnel (ammunition door adjustments), UU. Improved part (ammunition door: left side), UU. Changed mechanism of operation (of door cable assemblies), UU.	AH-1G
22b	Ammunition-Door Skin FM: Impact, fatigue, ductile rupture, bonding failure. FN: Protective covering, shielding. CA: Improved part (ammunition door: left side), UU. Changed mechanism of operation (of door cable assemblies), UU.	AH-1G
22c	Rivets FM: Impact, fatigue, ductile rupture, yielding. FN: Permanent fastening, attaching. CA: Direct replacement, UNI.	AH-1G
22d	Tail-Fin Drive Shaft Cover Hinge FM: Fatigue, wear. FN: Pivoting, supporting, motion constraining, attaching. CA: Change of material (Al. to corrosion resistant steel), UU. Changed dimensions (.090 dia to .118 dia hinge pin), UU.	AH-1G
22e	Tail-Fin Drive Shaft Cover FM: Fatigue, ductile rupture, wear, fretting-fatigue. FN: Protective covering, shielding. CA: Supplemental part (antichafing strip), UU. Supplemental part (steel bumper), UU. Changed method of attachment (eliminate interference with TR assy), UU.	AH-1G

TABLE XIV - Continued	
Case/Item	**Part Name** — **Helicopter Type/Model/Series** **FM: Failure Mode(s)** **FN: Function(s)** **CA: Corrective Action(s)**
22f	Access Door Panel Support Angles — AH-1G FM: Fatigue. FN: Supporting, attaching. CA: Changed dimensions (beefed-up angles), UU.
23	42° Gearbox Cover — AH-1G FM: Fatigue, yielding, ductile rupture, fretting-fatigue. FN: Protective covering, shielding, liquid constraining. CA: Changed dimension (thicker Kydex fairing), UU. Changed dimension (heavier Al. alloy), UU.
24a	Door — AH-1G FM: Yielding, impact. FN: Protective covering, viewing, shielding, light transmitting, pivoting. CA: Improved instructions to field personnel, UU. Improved part (new canopy), UU.
24b	Latch — AH-1G FM: Wear, impact. FN: Latching, motion constraining. CA: Improved part (new canopy), UU.
$24c_1$	Door Frame, Pilot — AH-1G FM: Impact, ductile rupture, fatigue. FN: Supporting, attaching. CA: Changed dimensions (by trimming door edge), UU.
$24c_2$	Door Frame, Gunner — AH-1G FM: Impact, ductile rupture, fatigue. FN: Supporting, attaching. CA: Supplemental part (gusset plate), UU.
24d	Handles — AH-1G FM: Ductile rupture. FN: Force transmitting, force amplifying.

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
24d (cont'd)	CA: Improved instructions to field personnel,UU. Improved part (new canopy). Added locking feature (screw to self-locking screw to prevent loosening), UU.	
24e	Door Seals FM: Ductile rupture, bonding failure. FN: Sealing, liquid constraining. CA: Improved part (new seal),UU. Provided drain (outer skin),UU.	AH-1G
24f	Handholds FM: Ductile rupture. FN: Supporting, force transmitting. CA: Direct replacement,UNI.	AH-1G
24g	Hinges FM: Ductile rupture, wear, fatigue, impact. FN: Pivoting, supporting, motion constraining, attaching. CA: Direct replacement,UNI.	AH-1G
24h	Door-Strut Ball Bearing FM: Wear. FN: Oscillatory rolling, supporting, friction reducing, motion constraining, pivoting. CA: Direct replacement,UNI.	AH-1G
25a	Engine Deck FM: Bonding Failure. FN: Supporting, protective covering. CA: Repaired part,UNI. Direct replacement,UNI.	AH-1G
25b	Tail Boom FM: Bonding failure. FN: Supporting, protective covering. CA: Repaired part,UNI. Direct replacement,UNI.	AH-1G
25c	Areas Underneath Weapons FM: Bonding failure. FN: Supporting, protective covering.	AH-1G

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
25c (cont'd)	CA: Repaired part, UNI, Direct replacement, UNI.	
25d	Battery Compartments FM: Bonding failure. FN: Supporting, protective covering. CA: Repaired part, UNI. Direct replacement, UNI.	AH-1G
26a	Fasteners FM: Yielding, ductile rupture, impact, fatigue, fretting-wear. FN: Removable fastening, attaching. CA: Changed dimensions of associated part (thicker covers and Kydex fairings), UU. Changed loading on part (replaced TAT-102A by XM-28 system), UU. Improved associated part (L.H. ammunition door), UU. Improved associated part (R.H. door assembly), UU.	AH-1G
26b	Rivets FM: Yielding, ductile rupture, fatigue, impact. FN: Permanent fastening, attaching. CA: Changed dimensions of associated part (thicker covers and Kydex fairings), UU. Changed loading on part (replaced TAT-102A by XM-28 system), UU. Improved associated part (L.H. ammunition door), UU. Improved associated part (R.H. door assembly), UU.	AH-1G
27a	Skid Shoes FM: Wear, impact, yielding. FN: Protective covering, sliding. CA: Changed dimensions (heavy-duty skid shoe), UU.	AH-1G
27b	Skid Tubes FM: Impact, ductile rupture, yielding. FN: Supporting. CA: Reinforced part (doublers), UU. Changed dimensions (thicker wall, longer doubler assy), UU.	AH-1G
27c	Cross Tubes FM: Yielding, impact. FN: Supporting, attaching. CA: Reinforced part (doublers), UU. Improved part, UU.	AH-1G

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
27d	Skid Shoe Screws FM: Improper dimension (length), insufficient elastic deformation. FN: Removable fastening, attaching. CA: Changed dimensions (longer screws), UU.	AH-1G
28	Cross-Tube Fairing FM: Ductile rupture, impact. FN: Streamlining. CA: Supplemental part (installed steps), UU.	AH-1G
29a	Thrust Bearings FM: Wear. FN: Oscillatory rolling, supporting, friction reducing, motion constraining. CA: Change of material (from 52100 to M50 steel). Improved instructions to field personnel (on thrust bearing lubrication). Changed loading on part (tractor tail rotor system), TIU.	AH-1G
29b	Pitch-Change Bearings FM: Wear. FN: Oscillatory sliding, supporting, force transmitting, motion constraining, friction reducing, pivoting. CA: Change of material (PTFE to Kacarb on bearing), UU. Changed loading on part (tractor tail rotor system), TIU.	AH-1G
29c	Hub Yoke Spindle FM: Ductile rupture, fatigue. FN: Supporting, attaching. CA: Improved part (new hub and yoke), UU. Changed loading on part (tractor tail rotor system), TIU.	AH-1G
29d	Tail Rotor Chain-Link Pins FM: Ductile rupture, fatigue. FN: Oscillatory sliding, linking, supporting, force transmitting. CA: Changed mechanism of operation (silent chain), UU.	AH-1G

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
29e	Tail Rotor Control Quill FM: Seizure, wear. FN: Sliding, supporting, force transmitting, torque transmitting. CA: Changed loading on part (tractor tail rotor system),TIU.	AH-1G
29f	Tail Rotor Slider FM: Wear. FN: Sliding, torque transmitting, supporting. CA: Changed loading on part (tractor tail rotor system), TIU.	AH-1G
30a	Gears FM: Scoring. FN: Torque transmitting, power transmitting. CA: Changed loading on part (tractor tail rotor system),UU.	AH-1G
30b	Mounting Studs FM: Fatigue, fretting-fatigue, ductile rupture. FN: Attaching, removable fastening, supporting. CA: Changed loading on part (operational movements limited). Improved instructions to field personnel (for proper installation of gearbox),UU.	AH-1G
30c	Mount Holes on Gearbox Case FM: Yielding. FN: Supporting, attaching. CA: Changed loading on part (operational movements limited, tractor tail rotor system incorporated). Improved instructions to field personnel (for proper installation of gearbox),UU.	AH-1G
30d	Seals FM: Leakage. FN: Sealing, liquid constraining. CA: Direct replacement,UNI.	AH-1G
31a	Skid Tube FM: Yielding, impact, ductile rupture, wear.	UH-1A,B,C,D,H

TABLE XIV - Continued	
Case/Item	Part Name — Helicopter Type/Model/Series FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)
31a (cont'd)	FN: Supporting. CA: Direct Replacement, UNI.
31b	Cross Tube — UH-1A,B,C,D,H FM: Yielding, impact, ductile rupture, wear. FN: Supporting, attaching. CA: Improved part, UNI.
31c	Cap Assembly — UH-1A,B,C,D,H FM: Impact, yielding, ductile rupture, wear. FN: Protective covering. CA: Improved part, UNI.
31d	Skid Shoe — UH-1A,B,C,D,H FM: Wear, impact, yielding, ductile rupture. FN: Protective covering, sliding. CA: Changed dimensions, UNI.
32a	Drive Shaft Hanger Bearing — UH-1A,B,C,D,H FM: Wear, lubrication failure, leakage, seizure, surface fatigue. FN: Continuous rolling, motion constraining, supporting, friction reducing. CA: Changed manufacturing procedure (quantity of lub.), UU. Improved part (seal of 623-1 bearing), UU. Changed lubricant type (new lubricant), UU. Changed method of lubrication (lubed to sealed brg.), UU.
32b	Tail Rotor Link Bearing — UH-1A,B,C,D,H FM: Wear. FN: Oscillatory sliding, supporting, force transmitting, motion constraining. CA: Improved associated part (new link assy), UU. Change of material (PTFE to Kacarb), UU.
32c	Crosshead — UH-1A,B,C,D,H FM: Scoring. FN: Force transmitting, linking. CA: Improved part (new crosshead and bushing), UU.

TABLE XIV - Continued	
Case/Item	**Part Name** — **Helicopter Type/Model/Series** **FM: Failure Mode(s)** **FN: Function(s)** **CA: Corrective Action(s)**
32d	Tail Rotor Yoke Spindle — UH-1A,B,C,D,H FM: Ductile rupture, fatigue. FN: Supporting, attaching. CA: Improved instructions to field personnel (inspection for cracks and damage),UU. Changed dimensions (increased nut outside diameter),UU. Changed loading on part (into yoke at groove rather than at retaining nut threads),UU. Supplemental part (retaining ring, spacer, radius ring, preload spring assembly),UU. Changed dimensions (grip thread dia., grip liner, grip retaining nut, grip seal, shims),UU.
32e	Safety Pin — UH-1A,B,C,D,H FM: Ductile rupture, fatigue. FN: Torque limiting. CA: Improved part (spiral lock pin),UU.
34a	Grip Bearing, Inboard — AH-1G FM: Wear, bonding failure, seizure. FN: Motion constraining, friction reducing, oscillatory sliding, supporting. CA: Direct replacement,UNI. Supplemental part (sand deflector added),UNI. Supplemental part (shield), UNI.
34b	Grip Bearing, Outboard — AH-1G FM: Wear, bonding failure, seizure. FN: Motion constraining, friction reducing, oscillatory sliding, supporting. CA: Direct replacement,UNI. Supplemental part (sand deflector added),UNI. Supplemental part (shield), UNI.
34c	Trunnion Bearing — AH-1G FM: Wear, surface fatigue. FN: Motion constraining, friction reducing, oscillatory sliding, supporting. CA: Direct replacement,UNI.

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
34d	Inboard Dust Seal FM: Leakage. FN: Sealing, contaminant constraining. CA: Direct replacement, UNI. Supplemental part (sand deflector added), UNI. Changed dimensions (added flange on inner ring), UNI.	AH-1G
34e	Outboard Dust Seal FM: Leakage. FN: Sealing, contaminant constraining. CA: Supplemental part (sand deflector added), UNI. Changed dimensions (added flange on inner ring), UNI.	AH-1G
36a	Lockout Valve FM: Leakage, ductile rupture. FN: Liquid switching, pressure limiting, sealing. CA: Changed mechanism of operation (unbalanced poppet to lap fitted spool and sleeve), UU.	AH-1G
36b	Relief Valve FM: Ductile rupture, leakage, fatigue. FN: Pressure limiting, sealing. CA: Eliminated part (relief valve), UU. Improved instructions to field personnel (for installation of relief valve until elimination becomes effective), UU.	AH-1G
36c	Solenoid Valve FM: Electrical. FN: Liquid switching, energy transforming, sealing. CA: Direct replacement, UNI.	AH-1G
37a	Hydraulic Servo Cylinder FM: Leakage. FN: Pressure supporting, force transmitting, force amplifying. CA: Direct replacement, UNI.	TH-1G
37b	Shaft Seals FM: Leakage.	TH-1G

TABLE XIV - Continued	
Case/Item	**Part Name** **Helicopter Type/Model/Series** **FM: Failure Mode(s)** **FN: Function(s)** **CA: Corrective Action(s)**
37b (cont'd)	FN: Sealing, liquid constraining. CA: Direct replacement, UNI.
38a	Lines AH-1G FM: Wear, ductile rupture, fatigue. FN: Liquid transferring, pressure supporting, liquid constraining. CA: Improved part (hydraulic system: limited results), UI.
38b	Fittings AH-1G FM: Ductile rupture, fatigue. FN: Attaching, supporting, sealing. CA: Improved part (hydraulic systems: limited results), UI. Change of material (elbows: Al. to St.), UU.
38c	Servos AH-1G FM: Leakage. FN: Pressure supporting, force transmitting, force amplifying. CA: Improved part (hydraulic system: limited results), UI.
38d	Cylinders AH-1G FM: Leakage. FN: Pressure supporting, force transmitting, force amplifying. CA: Improved part (hydraulic system: limited results), UI.
38e	Valves AH-1G FM: Leakage. FN: Liquid switching, liquid constraining, pressure supporting, sealing. CA: Improved part (hydraulic system: limited results), UI.
38f	Pumps AH-1G FM: Unknown. FN: Pumping, pressure increasing, liquid transferring, pressure supporting.

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
38f (cont'd)	CA: Improved part (hydraulic system: limited results), UI.	
38g	Seals FM: Leakage. FN: Sealing, liquid constraining. CA: Improved part (hydraulic system: limited results), UI.	AH-1G
38h	O-Rings FM: Leakage. FN: Sealing, liquid constraining. CA: Improved part (hydraulic system: limited results), UI.	AH-1G
39a	Tail Rotor Cables FM: Wear, fatigue. FN: Force transmitting, linking. CA: Improved instructions to field personnel (for rigging T.R.), UU. Applied surface coating (nylon coated cable), UU. Relocated part (for tractor tail rotor system), UU. Supplemental part (brackets, cable guides, idler sprocket, guards, stops), UU.	AH-1G
39b	Cable Fairleads FM: Wear. FN: Motion constraining, protective covering. CA: Improved instructions to field personnel (for rigging T.R.), UU. Applied surface coating (nylon coated cable), UU. Relocated part (for tractor tail rotor system), UU. Supplemental part (brackets, cable guides, idler sprocket, guards, stops), UU.	AH-1G
40a	Pylon Transducers FM: Leakage, corrosion. FN: Displacement indicating, signal transmitting. CA: Eliminated part (1 of 2 transducers removed), UU. Relocated part, UU. Improved part (cable assembly), UU.	AH-1G
40b	Valve Driver Module FM: Ductile rupture.	AH-1G

TABLE XIV - Continued	
Case/Item	**Part Name** **Helicopter Type/Model/Series** **FM: Failure Mode(s)** **FN: Function(s)** **CA: Corrective Action(s)**
40b (cont'd)	FN: Undefined. CA: Reinforced part (soldering: insure electrical connection), UU. Supplemental part (filter capacitor and wire shielding to eliminate interference), UU.
40c	Pylon Compensator AH-1G FM: Unknown. FN: Undefined. CA: Direct replacement, UNI.
40d	Printed Circuit Board AH-1G FM: Unknown. FN: Electrical insulating, electrical conducting. CA: Direct replacement, UNI.
41a	Elbow Ducts AH-1G FM: Ductile rupture, fatigue. FN: Gas constraining, gas transferring, guiding. CA: Supplemental part (replaceable filter), UU. Improved part (elbow duct), UU.
41b	Duct AH-1G FM: Ductile rupture, fatigue. FN: Gas constraining, gas transferring, guiding. CA: Improved part (duct), UU.
41c	Impeller Blades AH-1G FM: Ductile rupture, fatigue. FN: Pressure increasing, guiding. CA: Change of material (plastic to Al.), UU.
41d	Ventilation Valve AH-1G FM: Ductile rupture. FN: Gas switching, sealing. CA: Improved instructions to field personnel (sign: No Handhold), UU. Relocated part (valve), UU. Improved part, UU.

TABLE XIV - Continued	
Case/Item	Part Name / FM: Failure Mode(s) / FN: Function(s) / CA: Corrective Action(s) — Helicopter Type/Model/Series
41e	Temp Control Valve — AH-1G FM: Unknown. FN: Gas switching, sealing. CA: Direct replacement, UNI.
41f	Pressure Supply Line — AH-1G FM: Wear, leakage. FN: Gas transferring, gas constraining, pressure supporting. CA: Direct replacement, UNI.
42a	Horizontal Stabilizers — OH-6A FM: Ductile rupture, fatigue, impact, yielding. FN: Stabilizing, force transmitting. CA: Supplemental part (added weight), UU. Supplemental part (added damper), UU.
42b	Rivets — OH-6A FM: Ductile rupture, fatigue, impact. FN: Permanent fastening, attaching. CA: Supplemental part (added damper), UU.
43a	Windshield (Lower Assembly) — OH-6A FM: Erosion, impact, scoring, stress rupture. FN: Protective covering, viewing, shielding, light transmitting. CA: Change of material (polycarbonate instead of stretched acrylic), UU.
43b	Windshield (Top Assembly) — OH-6A FM: Erosion, scoring, stress rupture, impact. FN: Protective covering, viewing, shielding, light transmitting. CA: Direct replacement, UNI.
44a	Transmission Oil-Cooler Blower Scroll — OH-6A FM: Fatigue, ductile rupture. FN: Gas constraining, gas guiding, gas transferring, supporting. CA: Change of material (polycarbonate to fiberglass), R.

TABLE XIV - Continued		
Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
44b	Transmission Drain Assembly FM: Fatigue, ductile rupture. FN: Liquid transferring, liquid constraining. CA: Change of material (polycarbonate to fiberglass).	OH-6A
44c	Heater Ducts FM: Fatigue, ductile rupture. FN: Gas constraining, gas transferring, guiding. CA: Change of material (polycarbonate to fiberglass).	OH-6A
44d	Fuel Inlet Shield FM: Fatigue, ductile rupture. FN: Protective covering. CA: Change of material (polycarbonate to fiberglass).	OH-6A
44e	Junction Box FM: Fatigue, ductile rupture. FN: Electrical switching, electrical distributing, electrical limiting, electrical conducting. CA: Change of material (polycarbonate to fiberglass),R.	
44f	Log-Book Holder FM: Fatigue, ductile rupture. FN: Supporting. CA: Change of material (polycarbonate to fiberglass),R.	OH-6A
44g	Floor Support FM: Fatigue, ductile rupture. FN: Supporting, attaching. CA: Change of material (polycarbonate to Al.),R.	OH-6A
45a	Latches FM: Impact, fatigue, ductile rupture. FN: Latching. CA: Improved part,UU.	OH-6A
45b	Hinges FM: Impact, fatigue, ductile rupture, wear. FN: Pivoting, supporting, motion constraining, attaching. CA: Improved part,UU.	

TABLE XIV - Continued	
Case/Item	**Part Name** **Helicopter Type/Model/Series** **FM: Failure Mode(s)** **FN: Function(s)** **CA: Corrective Action(s)**
45c	Rivets OH-6A FM: Yielding, fatigue, ductile rupture. FN: Permanent fastening, attaching. CA: Direct replacement, UNI.
45d	Fasteners OH-6A FM: Yielding, fatigue, ductile rupture, wear. FN: Removable fastening, attaching. CA: Direct replacement, UNI.
45e	Cables OH-6A FM: Ductile rupture. FN: Force transmitting, linking. CA: Direct replacement, UNI.
45f	Handles OH-6A FM: Ductile rupture. FN: Force transmitting, force amplifying. CA: Direct replacement, UNI.
45g	Windows OH-6A FM: Brittle fracture, impact. FN: Protective covering, viewing, shielding, light transmitting. CA: Direct replacement, UNI.
45h	Hinge Spring OH-6A FM: Unknown. FN: Temporary latching, motion constraining, limiting. CA: Direct replacement, UNI.
45i	Emergency Release OH-6A FM: Unknown. FN: Removable fastening, supporting, pivoting. CA: Direct replacement, UNI.
45j	Hook OH-6A FM: Unknown. FN: Supporting, attaching, force transmitting. CA: Direct replacement, UNI.

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
45k	Bracket FM: Unknown. FN: Supporting, attaching. CA: Direct replacement, UNI.	OH-6A
46	Rivets FM: Impact, fatigue, yielding, ductile rupture. FN: Permanent fastening, attaching. CA: Changed method of attachment (rivets to screws for abrasion strips on tubes, and rivets to bolts for installation of tubes), UU. Changed loading on part (reduced vibration of T.R.), UU.	OH-6A
47a	Landing Gear Skid Tube FM: Wear, impact, yielding, ductile rupture. FN: Supporting. CA: Changed method of attachment (bolts), UU. Changed dimensions (thicker tube), UU. Made interchangeable parts to reduce inventory, UNI.	OH-6A
47b	Strut Assembly FM: Impact, yielding, ductile rupture, buckling. FN: Supporting, attaching. CA: Direct replacement, UNI.	OH-6A
47c	Strut Bracket FM: Impact, yielding, ductile rupture. FN: Supporting, attaching. CA: Direct replacement, UNI.	OH-6A
47d	Skid Fitting FM: Impact, yielding, ductile rupture. FN: Supporting, attaching. CA: Direct replacement, UNI.	OH-6A
47e	Abrasion Strip FM: Wear. FN: Protective covering, sliding. CA: Change of material, UU. Changed dimensions (increased wear area), UU. Supplemental part (added abrasion plate), UU.	OH-6A

TABLE XIV - Continued	
Case/Item	**Part Name** **Helicopter Type/Model/Series** **FM: Failure Mode(s)** **FN: Function(s)** **CA: Corrective Action(s)**
48a	Landing Gear Dampers OH-6A FM: Leakage, impact, wear. FN: Motion damping, energy absorbing, energy dissipating, motion reducing, stabilizing. CA: Improved part (different seal without backup),UU. Improved part (new one-piece cover),UU. Provided means for proper inspection (transparent cover and index bands),UU.
48b	Damper Bladder OH-6A FM: Ductile rupture, leakage. FN: Gas constraining, pressure supporting. CA: Direct replacement,UNI.
48c	Retainer OH-6A FM: Impact, ductile rupture, fatigue. FN: Limiting, supporting. CA: Change of material (Al. to steel),UU. Improved part (ring without lugs),UU.
49	Landing Gear Fairing OH-6A FM: Impact, bonding failure, ductile rupture, wear. FN: Streamlining, shielding. CA: Made interchangeable parts to reduce inventory,UNI. Supplemental part (Al. collar added),UU. Changed dimensions (made fairing thicker),UU. More easily replaceable (rivets and bonding to screws and nuts), UU. Changed method of attachment,UU.
50a	Tail Rotor Drive Shaft OH-6A FM: Impact, wear, ductile rupture, yielding, imbalance, fatigue. FN: Torque transmitting, power transmitting. CA: Changed dimensions (changed clearance for TR drive shaft by changing doubler),UU. Changed dimensions (thicker wall for drive shaft),UU.
50b	Coupling OH-6A FM: Impact, wear, ductile rupture, yielding, imbalance, fatigue.

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
50b (cont'd)	FN: Flexible coupling, torque transmitting, power transmitting. CA: Direct replacement, UNI.	
51a	Tail Rotor Teetering Bearing FM: Wear, bonding failure. FN: Motion constraining, friction reducing, oscillatory sliding, supporting. CA: Change of material of associated part (laminated to solid-steel shim), UU.	OH-6A
51b	Tail Rotor Hub FM: Corrosion, yielding. FN: Supporting, torque transmitting, attaching. CA: Direct replacement, UNI.	OH-6A
51c	Blade Tip Caps FM: Ductile rupture, bonding failure. FN: Streamlining, protective covering. CA: Supplemental part (added 2 rivets), UU. Changed adhesive material, UU.	OH-6A
51d	Blade Airfoil FM: Yielding, buckling. FN: Aerodynamic force transmitting, supporting, energy transforming. CA: Improved quality control (airfoil), UU. Improved part (steel and fiberglass to bonded-aluminum assembly), N.*	OH-6A
51e	Abrasion Strip FM: Bonding failure. FN: Protective covering, sliding. CA: Changed manufacturing procedure (material processing spec.), UU.	OH-6A
51f	Tail Rotor FM: Imbalance. FN: Stabilizing, guiding. CA: Change to correct part, UI.	OH-6A

TABLE XIV - Continued	
Case/Item	**Part Name** / **FM: Failure Mode(s)** / **FN: Function(s)** / **CA: Corrective Action(s)** — **Helicopter Type/Model/Series**
52a	Input Pinion Gear Shaft — OH-6A FM: Wear. FN: Torque transmitting, power transmitting. CA: Improved associated part (main transmission pump shims),UU. Changed method of lubrication,UU. Improved run-in procedure,UU. Improved part (different series of transmissions),UNI.
52b	Output Shaft — OH-6A FM: Unknown. FN: Torque transmitting, power transmitting. CA: Improved associated part (main transmission pump shims),UU. Changed method of lubrication,UU. Improved run-in procedure,UU. Improved part (different series of transmissions),UNI.
52c	Input Bevel Gear — OH-6A FM: Surface fatigue, wear, scoring. FN: Torque transmitting, power transmitting. CA: Improved associated part (main transmission pump shims),UU. Changed method of lubrication,UU. Improved run-in procedure,UU. Improved part (different series of transmissions),UNI.
52d	Transmission Shaft — OH-6A FM: Fatigue, ductile rupture. FN: Torque transmitting, power transmitting. CA: Changed manufacturing procedure (EB weld specification),UI. Changed vendor,UI. Improved quality control (ultrasonic EB weld inspection),UI.
52e	Bearing — OH-6A FM: Surface fatigue, corrosion, wear. FN: Continuous rolling, motion constraining, supporting, friction reducing. CA: Improved associated part (main transmission pump shims),UU. Changed method of lubrication,UU. Improved run-in procedure,UU. Improved part (improved high-speed roller bearings),UU. Improved part (different series of transmissions),UNI.

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
TABLE XIV - Continued		
52f	Bearing FM: Surface fatigue, corrosion, wear. FN: Continuous rolling, motion constraining, supporting, friction reducing. CA: Improved associated part (main transmission pump shims), UU. Changed method of lubrication, UU. Improved run-in procedure, UU. Improved part (improved high-speed roller bearings), UU. Improved Part (different series of transmissions), UNI.	OH-6A
52g	Bearing FM: Surface fatigue, corrosion, wear. FN: Continuous rolling, motion constraining, supporting, friction reducing. CA: Improved associated part (main transmission pump shims), UU. Changed method of lubrication, UU. Improved run-in procedure, UU. Improved part (improved high-speed roller bearings), UU. Improved part (different series of transmissions), UNI.	OH-6A
52h	Seals FM: Leakage. FN: Sealing. CA: Changed manufacturing procedure (improved main transmission oil pressure by eliminating internal leakage), UU. Improved part (different series of transmissions), UNI.	
53	Main Rotor Blades FM: Bonding failure, ductile rupture, erosion, impact, corrosion, delamination, fatigue. FN: Aerodynamic force transmitting, supporting, energy transforming. CA: Direct replacement, UNI.	OH-6A
54a	Pitch Control Bearing FM: Wear, surface fatigue. FN: Motion constraining, friction reducing, oscillatory sliding, supporting.	OH-6A

TABLE XIV - Continued	
Case/Item	Part Name / FM: Failure Mode(s) / FN: Function(s) / CA: Corrective Action(s) — Helicopter Type/Model/Series
54a (cont'd)	CA: Changed vendor, UU.
54b	Teetering Bearing — OH-6a FM: Wear, surface fatigue. FN: Motion constraining, friction reducing, oscillatory sliding, supporting. CA: Change of material (laminated to solid shims), UU.
54c	Tri-Plex Bearing — OH-6A FM: Wear, surface fatigue. FN: Continuous rolling, motion constraining, supporting, friction reducing. CA: Improved part, UU.
54d	Roller Bearing — OH-6A FM: Wear, surface fatigue. FN: Continuous rolling, motion constraining, supporting, friction reducing. CA: Changed vendor, UU. Applied surface treatment (hardness changed), UU. Changed lubricant type, UU. Improved lubrication (oil capacity increased), UU. Changed dimensions (roller and race changed), UU.
54e	Roller Bearing — OH-6A FM: Wear, surface fatigue. FN: Continuous rolling, motion constraining, supporting, friction reducing. CA: Improved lubrication (oil capacity increased), UU.
54f	Roller Bearing FM: Wear, surface fatigue. FN: Continuous rolling, motion constraining, supporting, friction reducing. CA: Change of material (52100 to M50 bearing material). Changed dimensions (closer tolerances). Applied surface coating (silver-plated roller cage).
54g	Annular Ball Bearing — OH-6A FM: Wear, surface fatigue. FN: Continuous rolling, motion constraining, supporting, friction reducing.

TABLE XIV - Continued		
Case/Item	**Part Name** **FM: Failure Mode(s)** **FN: Function(s)** **CA: Corrective Action(s)**	**Helicopter Type/Model/Series**
54g (cont'd)	CA: Change of material (52100 to M5C bearing material). Changed dimensions (closer tolerances).	
54h	Swashplate Bearing FM: Wear, surface fatigue. FN: Continuous rolling, supporting, friction reducing, motion constraining, force transmitting. CA: Changed manufacturing procedure (initial quantity of grease reduced; changed from machine to hand packing), UU.	OH-6A
54i	Bearing FM: Wear, surface fatigue. FN: Oscillatory rolling, supporting, friction reducing, motion constraining, pivoting, force transmitting. CA: Direct replacement, UNI.	OH-6A
54j	Bearing FM: Wear, surface fatigue. FN: Oscillatory rolling, supporting, friction reducing, motion constraining, pivoting. CA: Direct replacement, UNI.	OH-6A
54k	Bearing FM: Wear, surface fatigue. FN: Motion constraining, friction reducing, oscillatory sliding, supporting. CA: Direct replacement, UNI.	OH-6A
54L	Bearing FM: Wear, surface fatigue. FN: Oscillatory sliding, supporting, force transmitting, motion constraining, friction reducing, pivoting. CA: Direct replacement, UNI.	OH-6A
55	Battery FM: Electrochemical overheating, leakage. FN: Energy storing, energy transforming. CA: Changed vendor. Change of material (different insulation). Changed method of attachment (different installation fittings).	OH-6A

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
56	Armor Side-Panel Latch Pin FM: Ductile rupture. FN: Latching, attaching, removable fastening. CA: Changed dimensions (deeper pin engagement),UU. Adjusted part (shim added). Supplemental part (shim added).	OH-58A
57a	Latches FM: Ductile rupture, yielding, fatigue, impact. FN: Latching, attaching. CA: Changed dimensions (latch rod: L.H. crew and passenger doors),UU. Supplemental part (peel shim: L.H. crew and passenger doors),UU.	OH-58A
57b	Liner FM: Ductile rupture, yielding, fatigue, impact. FN: Protective covering. CA: Direct replacement,UNI.	OH-58A
57c	Latch Pin FM: Ductile rupture, yielding, fatigue, impact. FN: Removable fastening, attaching. CA: Changed dimensions (latch rod: L.H. crew and passenger doors),UU.	OH-58A
57d	Door Latch Spring FM: Ductile rupture, yielding, fatigue, impact. FN: Position restoring, force transmitting. CA: Relocated part (aft spring: L.H. crew and passenger doors),UU.	OH-58A
57e	Doors FM: Fatigue, ductile rupture, impact. FN: Protective covering, viewing, shielding, light transmitting, pivoting. CA: Repositioned associated part (roller assy: L.H. crew and passenger doors),UU. Supplemental part (peel shim: L.H. crew and passenger doors),UU. Improved part (passenger door handle),UU. Changed dimensions (thickened skin),UU.	OH-58A

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
58a	Dzus Fasteners FM: Ductile rupture, fatigue, wear. FN: Removable fastening, attaching. CA: Direct replacement, UNI.	OH-58A
58b	Rivets FM: Fatigue, yielding, ductile rupture, impact. FN: Permanent fastening, attaching. CA: Direct replacement, UNI.	OH-58A
59a	Drive Shaft FM: Corrosion, wear. FN: Power transmitting, torque transmitting. CA: Improved instructions to field personnel (shaft alignment), UU.	OH-58A
59b	Rubber Collar FM: Seizure, wear. FN: Attaching, motion constraining, flexible spacing. CA: Improved part, UU. Direct replacement, UNI.	OH-58A
59c	Bearing FM: Wear, seizure. FN: Continuous rolling, motion constraining, supporting, friction reducing. CA: Improved part, UU. Improved part, TNI.	OH-58A
60a	Drive Shaft Assembly FM: Wear. FN: Torque transmitting, power transmitting. CA: Direct replacement, UNI.	OH-58A
60b	Coupling Seal FM: Ductile rupture, change in material property, wear. FN: Sealing, contaminant constraining. CA: Changed dimensions of associated part (cut $\frac{1}{4}$" from cone), UU. Changed dimensions, TIU. Change of material (Hydren base with Nomex cloth), TIU.	OH-58A

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
61a	Tail Rotor Trunnion FM: Wear, yielding. FN: Motion constraining, friction reducing, sliding, supporting. CA: Improved instructions to field personnel, (inspecting and adjusting preload), UU.	OH-58A
61b	Pitch Change Bearing FM: Wear. FN: Oscillatory sliding, supporting, force transmitting, motion constraining, friction reducing, pivoting. CA: Changed manufacturing procedure (roll staking instead of ring staking), UU.	OH-58A
62a	Flight Control Servo Seal FM: Wear, leakage. FN: Sealing, liquid constraining. CA: Improved part (new actuator), UU.	OH-58A
62b	Actuator Rod FM: Scoring, corrosion. FN: Linking, force transmitting, supporting. CA: Improved part (new actuator), UU.	OH-58A
63a	Fasteners FM: Ductile rupture, fatigue, yielding, impact, wear. FN: Removable fastening, attaching. CA: Changed method of attachment (camlock to screws), UU. Changed loading on part (reduced vibrations), UU. Improved associated part (tunnel covers), UU. Change of material of associated part (fiberglass to honeycomb tunnel covers), UU.	CH-47A,B,C
63b	Rivets FM: Ductile rupture, fatigue, yielding, impact, fretting-wear. FN: Permanent fastening, attaching. CA: Changed loading on part (reduced vibrations), UU. Improved associated part (tunnel covers), UU. Change of material of associated part (fiberglass	CH-47A,B,C

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
63b (cont'd)	to honeycomb tunnel covers),UU. Direct replacement, UNI.	
64	Windshield FM: Delamination, scoring, stress rupture. FN: Protective covering, viewing, shielding, light transmitting. CA: Change of material (plexiglass layers to glass-faced plexiglass laminates),UU. Improved associated part (wiper blades),UU.	CH-47A,B,C
65a	Tunnel Access Covers FM: Ductile rupture, fatigue, galling, yielding. FN: Protective covering, shielding. CA: Reinforced part (added stiffeners to covers),UU. Supplemental part (added struts to N1 and N5 covers),UU. Change of material (fiberglass to Al. honeycomb),UU. Strengthened part (fiberglass to Al. honeycomb),UU. Change of material (fiberglass to Al.),UU.	CH-47A,B,C
65b	Pylon Hinged Fairing FM: Ductile rupture, fatigue, galling. FN: Streamlining, shielding, protective covering. CA: Change of material (fiberglass to fiberglass skin on nylon honeycomb),UU. Supplemental part (added Al. strip covered with antichafing strip),UU. Reinforced part (Al. stiffening strip),UU.	CH-47A,B,C
65c	Lower Pylon Fixed Fairing FM: Ductile rupture, fatigue. FN: Streamlining, shielding, protective covering. CA: Changed method of attachment (made parts of fairing separate access doors),UU. Changed dimensions,UU.	CH-47A,B,C
65d	Rivet Hole Region in Fiberglass FM: Yielding, ductile rupture, fatigue. FN: Attaching. CA: Direct replacement,UNI. Repaired part,UNI.	CH-47A,B,C

TABLE XIV - Continued	
Case/Item	**Part Name** **Helicopter Type/Model/Series** **FM: Failure Mode(s)** **FN: Function(s)** **CA: Corrective Action(s)**
65e	Latches CH-47A,B,C FM: Wear. FN: Latching, attaching. CA: Improved part (latch),UU.
65f	Tunnel Cover Struts CH-47A,B,C FM: Ductile rupture, fatigue. FN: Temporary supporting, force transmitting. CA: Eliminated part (tunnel cover struts),UU. Changed mechanism of operation (hinged hold-open strut instead of straight strut),UU.
65g	Synchronized Shafting CH-47A,B,C FM: Scoring. FN: Torque transmitting, power transmitting. CA: Direct replacement,UNI.
66a	Platforms CH-47A,B,C FM: Ductile rupture, fatigue. FN: Supporting, covering. CA: Improved part (modified fwd work platforms),UU. Improved part (aft pylon work platform),UU. Reinforced part (pylon work platform),UU. Reinforced part (add partial former: pod fairing), UU. Changed dimensions of associated part (prevent chafing between forward stiffener and strut adapter),UU.
66b	Doors CH-47A,B,C FM: Ductile rupture, fatigue, impact. FN: Protective covering, viewing, shielding, light transmitting, pivoting. CA: Direct replacement,UNI.
66c	Hinges CH-47A,B,C FM: Yielding, wear, ductile rupture, fatigue. FN: Pivoting, supporting, motion constraining, attaching. CA: Direct replacement,UNI.

TABLE XIV - Continued	
Case/Item	**Part Name** / **FM: Failure Mode(s)** / **FN: Function(s)** / **CA: Corrective Action(s)** — **Helicopter Type/Model/Series**
66d	Latches — CH-47A,B,C FM: Yielding, wear, ductile rupture, fatigue, impact. FN: Latching, attaching. CA: Strengthened part (used heavier duty latches),UU. Supplemental part (added latch on upper edge of platform),UU. Reinforced associated part (reinforced former).
66e	Struts — CH-47A,B,C FM: Ductile rupture, fatigue, yielding. FN: Temporary supporting, force transmitting. CA: Direct replacement,UNI.
66f	Gussets — CH-47A,B,C FM: Ductile rupture, fatigue, yielding. FN: Attaching, reinforcing. CA: Direct replacement,UNI.
66g	Platform Support — CH-47A,B,C FM: Fatigue, elastic deformation. FN: Supporting. CA: Direct replacement,UNI.
67a	Cargo Door — CH-47A,B,C FM: Impact, yielding, corrosion. FN: Protective covering, shielding, supporting. CA: Provided drain (drain holes added),UU.
67b	Hinges — CH-47A,B,C FM: Fatigue, corrosion, ductile rupture. FN: Attaching, supporting, pivoting, limiting, motion constraining. CA: Improved instructions to field personnel (periodic cleaning during inspection),UU.
68a	Skin — CH-47A,B,C FM: Ductile rupture, fatigue. FN: Shielding, supporting, protective covering. CA: Reinforced part (stringer and skin at stations 110 and 419),UU.

Case/Item	Part Name / FM: Failure Mode(s) / FN: Function(s) / CA: Corrective Action(s)	Helicopter Type/Model/Series
68b	Stringers FM: Ductile rupture, fatigue. FN: Reinforcing, supporting. CA: Improved part (engine mount support at station 482), UU. Reinforced part (stringer and skin at stations 110 and 419), UU.	CH-47A,B,C
68c	Bulkheads FM: Ductile rupture, fatigue. FN: Supporting, partitioning. CA: Reinforced associated part, UU.	CH-47A,B,C
68d	Formers FM: Ductile rupture, fatigue. FN: Shape constraining, reinforcing, supporting. CA: Reinforced part (hub flanges at station 5029437), UU. Improved part (frame at station 482), UU. Improved part (modified side frame at station 482), UU. Improved part (modified aft pylon former at station 502), UU.	CH-47A,B,C
69a	Engine Mount Fittings FM: Scoring, fatigue, ductile rupture, wear. FN: Supporting, attaching, force transmitting. CA: Supplemental part (TFE spacer added), UU. Repaired part (used oversize bushing in holes), UNI. Supplemental part (fiberglide bearing liners in link assembly), UU. Improved part (forward engine mount), UU. Improved part (aft engine mount), UU. Improved associated part (drag strut), UU.	CH-47A,B,C
69b	Bushings FM: Yielding. FN: Force distributing, supporting. CA: Supplemental part (added steel sleeve), UU.	CH-47A,B,C
70	Floor Beam Assembly FM: Corrosion. FN: Supporting, attaching. CA: Change of material (magnesium to Al. rails), UNI. Repaired part (clean up corrosion and add	CH-47A,B,C

TABLE XIV - Continued	
Case/Item	**Part Name** **Helicopter Type/Model/Series** **FM: Failure Mode(s)** **FN: Function(s)** **CA: Corrective Action(s)**
70 (cont'd)	corrosion preventive), UNI. Applied surface coating (corrosion preventive), UU.
71	Main Rotor Blades CH-47A,B,C FM: Bonding failure, delamination, erosion, impact, corrosion, ductile rupture, fatigue, yielding. FN: Aerodynamic force transmitting, supporting, energy transforming. CA: Improved part (M.R. blade), UU. Improved part (tip cover assemblies), UU. Improved instructions to field personnel (inspection of blades), UU. Added adhesive (between core and skins, FM-1000), UU. Provided drain, UU. Added sealant (adhesive used as sealant to plug hole), UU. Reinforced part (tip fairing), UU. Changed dimensions (enlarged tiedown hole), UU. Reinforced part (reinforced tiedown hole), UU. Improved part (root, basic, and tip fairing assemblies), UU.
72	Rotor Hub Oil Tank Spring Lugs CH-47A,B,C FM: Wear. FN: Attaching, supporting, force transmitting. CA: Change of material of associated part (nonmetallic washer), UU.
73a	Shock Mount Springs CH-47A,B,C FM: Ductile rupture, fatigue, yielding. FN: Flexible supporting, attaching, limiting, energy distributing. CA: Improved associated part (shaft assemblies), UU. Strengthened associated part (airframe stiffened), UU. Changed loading on part (reduced mount loading), UU. Improved instructions to field personnel (recommended items to check for discrepancies), UU. Direct replacement (if other techniques fail), UNI. Improved part (synchronized shaft adapter), UNI. Improved part (shaft adapter and lugs), UU. Supplemental part (brackets added), UU. Changed mechanism of operation (spring to elastomeric mount), TNI.[9]

TABLE XIV - Continued	
Case/Item	**Part Name** / **Helicopter Type/Model/Series** **FM: Failure Mode(s)** **FN: Function(s)** **CA: Corrective Action(s)**
73b	Bearing — CH-47A,B,C FM: Wear. FN: Continuous rolling, motion constraining, supporting, friction reducing. CA: Improved associated part (shaft assemblies),UU. Strengthened associated part (airframe stiffened), UU. Changed dimensions (ball to cage clearance),UU. Improved instructions to field personnel (recommended items to check for discrepancies),UU. Direct replacement (if other techniques fail),UNI. Improved part (synchronized shaft adapter),UNI. Improved part (shaft adapter and lugs),UU.
74	Trans. Oil Pressure Transducer — CH-47A,B,C FM: Electrical. FN: Pressure indicating, signal transmitting. CA: Improved part (transducer),UU.
75	Pitch Varying Housing Seal — CH-47A,B,C FM: Wear, leakage. FN: Sealing, liquid constraining. CA: Supplemental part (added wear sleeve/debris baffle),UU. Changed mechanism of operation (located seal and debris baffle on different surfaces),UU.
76a	Annular Ball Bearing — CH-47A,B,C FM: Wear, seizure, leakage, galling, surface fatigue. FN: Continuous rolling, motion constraining, supporting, friction reducing. CA: Direct replacement,UNI.
76b	Bearing — CH-47A,B,C FM: Wear, seizure, leakage, galling. FN: Oscillatory sliding, supporting, force transmitting, motion constraining, friction reducing, pivoting. CA: Change of material (fabroid to fiberglide bearing surface),UU.

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
76c	Plain Rod End Bearing FM: Wear, seizure, leakage, galling. FN: Oscillatory sliding, supporting, force transmitting, motion constraining, friction reducing, pivoting. CA: Change of material (fabroid to fiberglide bearing surface), UU.	CH-47A,B,C
76d	Sleeve Bearing FM: Wear, seizure, leakage, galling. FN: Oscillatory sliding, supporting, force transmitting, motion constraining, friction reducing, pivoting. CA: Direct replacement, UNI.	CH-47A,B,C
76e	Plain Rod End Bearing FM: Wear, seizure, leakage, galling. FN: Oscillatory sliding, supporting, force transmitting, motion constraining, friction reducing, pivoting. CA: Improved part (lower pitch link rod end bearing), UU. Change of material (fabroid to fiberglide bearing surface), UU.	CH-47A,B,C
76f	Plain Bearing FM: Wear, seizure, leakage, galling. FN: Oscillatory sliding, supporting, force transmitting, motion constraining, friction reducing, pivoting. CA: Improved part (lower pitch link rod end bearing), UU. Change of material (fabroid to fiberglide bearing surface), UU.	CH-47A,B,C
76g	Self-Aligning Bearing FM: Wear, seizure, leakage, galling. FN: Oscillatory sliding, supporting, force transmitting, motion constraining, friction reducing, pivoting. CA: Change of material (fabroid to fiberglide bearing surface), UU.	CH-47A,B,C

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
76h	Self-Aligning Bearing FM: Wear, seizure, leakage, galling. FN: Oscillatory sliding, supporting, force transmitting, motion constraining, friction reducing, pivoting. CA: Change of material (fabroid to fiberglide bearing surface), UU.	CH-47A,B,C
76i	Self-Aligning Bearing FM: Wear, seizure, leakage, galling. FN: Oscillatory sliding, supporting, force transmitting, motion constraining, friction reducing, pivoting. CA: Direct Replacement, UNI.	CH-47A,B,C
76j	Self-Aligning Bearing FM: Wear, seizure, leakage, galling. FN: Oscillatory sliding, supporting, force transmitting, motion constraining, friction reducing, pivoting. CA: Direct replacement, UNI.	CH-47A,B,C
76k	Flight Control Bearing FM: Wear, seizure, leakage, galling. FN: Oscillatory sliding, supporting, force transmitting, motion constraining, friction reducing, pivoting. CA: Change of material (fabroid to fiberglide bearing surface), UU.	CH-47A,B,C
76L	Flight Control Bearing FM: Wear, seizure, leakage, galling. FN: Oscillatory sliding, supporting, force transmitting, motion constraining, friction reducing, pivoting. CA: Change of material (fabroid to fiberglide bearing surface), UU.	CH-47A,B,C
76m	Bearing Liners FM: Wear. FN: Supporting, attaching, motion constraining. CA: Direct replacement, UNI.	CH-47A,B,C

TABLE XIV - Continued	
Case/Item	**Part Name** **Helicopter Type/Model/Series** **FM: Failure Mode(s)** **FN: Function(s)** **CA: Corrective Action(s)**
77a	Servos CH-47A,B,C FM: Leakage. FN: Pressure supporting, force transmitting, force amplifying. CA: Direct replacement,UNI.
77b	Cylinders CH-47A,B,C FM: Leakage FN: Pressure supporting, force transmitting, force amplifying. CA: Direct replacement,UNI.
77c	Pumps CH-47A,B,C FM: Ductile rupture, leakage. FN: Pumping, pressure increasing, liquid transferring, pressure supporting. CA: Improved part (modified pump handle),UI. Improved part (replace pump),UI.
77d	Filters CH-47A,B,C FM: Unknown. FN: Filtering, contaminant constraining. CA: Supplemental part (install filter),UI. Improved part (filter modification),UI. Eliminated part (filter bypass),UI. Supplemental part (add filter indicators),UI.
77e	Valves CH-47A,B,C FM: Leakage. FN: Liquid switching, liquid constraining, pressure supporting, sealing. CA: Improved part (replace control valve),UI. Improved part (replace valves),UI. Supplemental part (add check valve),UI. Improved part (reduce relief valve pressure),UI.
77f	Motors CH-47A,B,C FM: Unknown. FN: Pressure-to-torque transforming, liquid constraining,torque transmitting. CA: Direct replacement,UNI.

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
77g	Lines FM: Ductile rupture, leakage, fatigue. FN: Liquid transferring, pressure supporting, liquid constraining. CA: Relocated part (reroute lines), UI. Improved part (replace lines), UI. Supplemental part (add check valve), UI.	CH-47A,B,C
77h	Tubes FM: Ductile rupture, leakage, fatigue. FN: Liquid transferring, pressure supporting, liquid constraining. CA: Direct replacement, UNI.	CH-47A,B,C
77i	Seals FM: Leakage. FN: Sealing, liquid constraining. CA: Direct replacement, UNI	CH-47A,B,C
77j	Connections FM: Ductile rupture, leakage, fatigue. FN: Attaching, supporting, sealing. CA: Improved part (replace swivel lock manifold), UI.	CH-47A,B,C
78a	Voltage Regulator FM: Unknown. FN: Electrical limiting, electrical conducting, sensing, stabilizing. CA: Changed electrical characteristics (changed resistor), UU. Improved part (combined regulator and protection panel), UU. Changed electrical characteristics (increased transistor rating from 200 to 250 volts and changed diode rating from 400 to 600 volts).	CH-47A,B,C
78b	Protection Panel FM: Unknown. FN: Undefined. CA: Improved part (combined regulator and protection panel), UU.	CH-47A,B,C

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
78c	Power Distribution Panel FM: Unknown. FN: Undefined. CA: Supplemental part (added diodes and capacitors), UU. Changed manufacturing procedure (improved connector crimping process), UU. Improved part (improved panels).	CH-47A,B,C
79a	SAS Variable Resistor FM: Wear. FN: Electrical reducing, electrical conducting, power absorbing. CA: Improved part (transducer for variable resistor), UU. Improved instructions to field personnel (color coding for electrical connectors), UU.	CH-47A,B,C
79b	Valves, Electro-Hydraulic FM: Leakage. FN: Liquid switching, liquid constraining, pressure supporting, sealing, energy transforming. CA: Improved instructions to field personnel (color coding of hydraulic lines), UU. Improved part (elec-hydraulic servo valve), UU. Improved part (accumulators and drains), UU.	CH-47A,B,C
79c	Cylinders FM: Leakage. FN: Pressure supporting, force transmitting, force amplifying. CA: Improved instructions to field personnel (color coding of hydraulic lines), UU. Improved part accumulators and drains), UU.	CH-47A,B,C
79d	Linear Valve FM: Leakage. FN: Liquid switching, liquid constraining, pressure supporting, sealing. CA: Improved instructions to field personnel (color coding of hydraulic lines), UU. Improved part, UU.	CH047A,B,C

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
80	Radio Set AN/ARC-54 FM: Unknown. FN: Electrical amplifying, electrical transmitting. CA: Improved part (AN-131 for AN/ARC-54).	CH-47A,B,C
81a	Main Rotor Blades FM: Impact, ductile rupture, fatigue, erosion, bonding failure, yielding. FN: Aerodynamic force transmitting, supporting, energy transforming. CA: Improved instructions to field personnel (blade corrosion inspection).	CH-54A
81b	Tip Cap FM: Fatigue, ductile rupture, erosion, elastic deformation, imbalance. FN: Streamlining, protective covering. CA: Applied surface coating (tip cap leading edge, nickel-plated),UU. Improved part (tip cap),UU. Supplemental part (incorporates balance weights), UU. Supplemental part (hard nickel abrasion strip),UU.	CH-54A
81c	BIM Indicator FM: Leakage. FN: Indicating. CA: Direct replacement,UNI.	CH-54A
81d	Balance Plate Studs FM: Fatigue. FN: Attaching, supporting. CA: Changed to correct part (used correct strength stud),UI. Direct replacement,UNI.	CH-54A
81e	Spar Seals FM: Yielding, leakage. FN: Sealing, contaminant constraining. CA: Direct replacement,UNI.	CH-54A

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
82a	Tail Rotor Blades FM: Bonding failure, ductile rupture, erosion, fatigue. FN: Aerodynamic force transmitting, supporting, energy transforming. CA: Improved part (new provisions for balancing blade). Strengthened part (respaced ribs in pocket),UU. Improved instructions to field personnel (provision for repair),UU.	CH-54A
82b	Tip Cap Assembly FM: Erosion, bonding failure. FN: Streamlining, protective covering. CA: Reinforced part (added 2 ribs),UU. Changed dimension (cord made longer; added rivet attachment points),UU. Applied surface coating (nickel plate leading edge),UU. Change of material (stainless steel bonded abrasion strip to hard nickel plating),UU.	CH-54A
83a	Rotor Brake Shaft Seal FM: Fatigue, scoring, brittle fracture. FN: Sealing. CA: Direct replacement,UNI.	CH-54A,B
83b	Rotor Brake Disc FM: Imbalance. FN: Energy absorbing, energy dissipating, motion reducing, sliding, torque transmitting. CA: Direct replacement,UNI. Changed loading on part (thick rotor brake disc).	CH-54A,B
84	Rotor Brake Support Bracket FM: Fatigue. FN: Supporting, attaching. CA: Change of material (Al. to MIL-S-5059 stainless steel),UU. Strengthened part (Al. to steel),UU. Relocated parts (rotor brake package and support bracket),UU.	CH-54A

TABLE XIV - Continued	
Case/Item	**Part Name** / **Helicopter Type/Model/Series** **FM: Failure Mode(s)** **FN: Function(s)** **CA: Corrective Action(s)**
85	Main Rotor Brake Disc — CH-54A FM: Wear, seizure, ductile rupture, fatigue, yielding, imbalance. FN: Energy absorbing, energy dissipating, motion reducing, sliding, torque transmitting. CA: Improved instructions to field personnel (measure wear and run-out on brake disc within limits every 100 hours),UU. Changed dimensions (thinner and lighter disc, thicker linings),UU.
86	Rotor Brake Assembly Pucks — CH-54A FM: Wear, ductile rupture. FN: Energy absorbing, energy dissipating, force transmitting. CA: Improved part (rotor brake package),UU. Changed loading on part (soft stop braking),UU.
87a	Gearbox Oil Cooler V-Belts — CH-54A FM: Wear, improper dimension (length). FN: Torque transmitting, force transmitting. CA: Improved quality control (matched V-belts),UU.
87b	Idler Pulley Bearing — CH-54A FM: Wear. FN: Continuous rolling, motion constraining, supporting, friction reducing. CA: Improved part (pulleys and pulley assy),UU.
87c	Pulleys — CH-54A FM: Wear. FN: Torque transmitting, motion constraining, supporting. CA: Improved part (pulleys and pulley assy),UU.
88a	O-Ring — CH-54A,B FM: Leakage. FN: Sealing, liquid constraining. CA: Direct replacement,UNI.

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
88b	Carbon Seal FM: Brittle fracture, fatigue, wear. FN: Sealing, liquid constraining. CA: Direct replacement, UNI.	CH-54A,B
89a	Main Rotor Shaft Plug FM: Yielding, bonding failure. FN: Covering, sealing. CA: Changed dimensions (greater diameter of cork plugs), UU. Supplemental part (breather assy on plug) UU. Relocated part (6" above previous position), UU. Added sealant (epoxy cement EC-1751), UU.	CH-54A
89b	Oil Pressure Switch FM: Corrosion, leakage. FN: Electrical switching, pressure supporting, pressure sensing, electrical conducting. CA: Direct replacement, UNI.	CH-54A
89c	Main Gearbox FM: Wear, scoring, corrosion. FN: Sealing, covering. CA: Improved instructions to field personnel (oil contamination), UU. Improved associated part (oil pump from gear to vane type), UU. Supplemental part (sleeve and seal housing for main rotor shaft drain), UU.	CH-54A
90a	Viscous Damper FM: Leakage, wear. FN: Motion damping, energy absorbing, energy dissipating, motion reducing, stabilizing. CA: Improved instructions to field personnel (installation of viscous dampers), UU. Improved associated part (removal of all primer/paint from outer spacer). Improved part (bag-type viscous damper). Direct replacement, UNI.	CH-54A,B
90b	Rubber Strip FM: Elastic deformation, change in material property, ductile rupture, leakage, wear.	CH-54A,B

TABLE XIV - Continued	
Case/Item	**Part Name** — **Helicopter Type/Model/Series** **FM: Failure Mode(s)** **FN: Function(s)** **CA: Corrective Action(s)**
90b (cont'd)	FN: Sealing, flexible spacing. CA: Improved part (bag-type viscous damper), Direct replacement, UNI.
91a	Seal Lip — CH-54A FM: Wear, leakage. FN: Sealing, liquid constraining. CA: Improved instructions to field personnel (inspection TR head assy), UU. Strengthened part (3/8 to 1/2 dia), UU.
91b	Spindle — CH-54A FM: Scoring. FN: Supporting, attaching. CA: Improved instructions to field personnel (inspection TR head assy), UU. Improved part (improved sleeve, spindle, hub), UU.
91c	Spherical Bearing — CH-54A FM: Wear. FN: Oscillatory sliding, supporting, force transmitting, motion constraining, friction reducing, pivoting. CA: Improved instructions to field personnel (inspection and wear limits spec.), UU. Improved instructions to field personnel (inspection TR head assy), UU. Changed dimensions (increased ball diameter), UU. Improved part (pitch link assy), UU. Improved part (new rod end assy), UU. Change of material (second generation PTFE liner bearings), TIU.
91d	Rod End — CH-54A FM: Fatigue. FN: Attaching, supporting, linking, force transmitting. CA: Improved instructions to field personnel (inspection TR head assy), UU. Changed dimensions (increased rod end diameter), UU. Improved instructions to field personnel, UU. Improved part (pitch link assy), UU. Supplemental part (added integral counterweight), UU.

TABLE XIV - Continued	
Case/Item	**Part Name** / **FM: Failure Mode(s)** / **FN: Function(s)** / **CA: Corrective Action(s)** — **Helicopter Type/Model/Series**
92a	Generator Shaft — CH-54A,B FM: Ductile rupture. FN: Torque transmitting. CA: Applied surface coating (tungsten-carbide flame plated coating to reduce wear), UI. Changed method of lubrication (pressurized lubrication), UI.
92b	GEU7A Tachometer Shaft — CH-54A,B FM: Ductile rupture. FN: Torque transmitting, supporting. CA: Direct replacement, UNI.
92c	Seal — CH-54A,B FM: Leakage. FN: Sealing, liquid constraining. CA: Direct replacement, UNI.
92d	Slip Ring — CH-54A,B FM: Brittle fracture, ductile rupture. FN: Sliding, electrical conducting. CA: Direct replacement, UNI.
93a	Hoist Pump — CH-54A FM: Leakage. FN: Pumping, pressure increasing, liquid transferring, pressure supporting. CA: Improved instructions to field personnel (inspection of control valves), UU. Direct replacement, UNI. Improved part.
93b	Microswitch — CH-54A FM: Corrosion, leakage. FN: Electrical switching, electrical conducting. CA: Improved instructions to field personnel (inspection of control valves), UU. Direct replacement, UNI. Improved part.
94a	O-Rings — CH-54A FM: Ductile rupture, leakage, wear, yielding. FN: Sealing, contaminant constraining. CA: Improved part (banjo fittings replaced), UU.

TABLE XIV - Continued	
Case/Item	**Part Name** **Helicopter Type/Model/Series** **FM: Failure Mode(s)** **FN: Function(s)** **CA: Corrective Action(s)**
94a (cont'd)	Improved instructions to field personnel (banjo fitting discrepancies), UU. Change of material (MS type O-ring to viton "A" in 66W series pumps), UU.
94b	Banjo fittings CH-54A FM: Fatigue, ductile rupture, leakage. FN: Attaching, supporting, pivoting, liquid transferring. CA: Improved part (banjo fittings replaced), UU. Relocated part (rerouted tube assy), UU. Improved part (flexible hose instead of rigid hose), UU. Changed mechanism of operation (4 piece to 3 piece fitting), UU. Supplemental part (walk panel), UU. Supplemental part (metal cover for protection), UU. Improved instructions to field personnel (banjo fitting discrepancies), UU.
95a	Servo Valve CH-54A, B FM: Leakage, wear. FN: Liquid switching, liquid constraining, pressure supporting, sealing. CA: Direct replacement, UNI. Improved instructions to field personnel (AFCS amplified maintainability improvements). Improved part (incorporate redundant structures in servo valve link). Improved part (dust boot).
95b	Open-Loop Spring CH-54A, B FM: Improper dimension (length). FN: Force maintaining, stabilizing, position restoring. CA: Direct replacement (of entire units), UNI. Improved instructions to field personnel (AFCS amplified maintainability improvements). Improved part (incorporate redundant structures in servo valve link). Adjusted part, UI. Improved part (dust boot).
96a	Tubes CH-54A, B FM: Fatigue, ductile rupture, leakage.

TABLE XIV - Continued

Case/Item	Part Name / FM: Failure Mode(s) / FN: Function(s) / CA: Corrective Action(s)	Helicopter Type/Model/Series
96a (cont'd)	FN: Liquid transferring, pressure supporting, liquid constraining. CA: Change of material of associated part (phenolic to rubber support block), UU.	
96b	Hoses FM: Fatigue, ductile rupture, leakage, wear. FN: Liquid transferring, pressure supporting, liquid constraining. CA: Direct replacement, UNI.	CH-54A,B
96c	Housings and Manifolds FM: Fatigue, ductile rupture, leakage. FN: Attaching, supporting, pivoting, liquid transferring. CA: Direct replacement, UNI.	CH-54A,B
96d	Pumps FM: Leakage, wear. FN: Pumping, pressure increasing, liquid transferring, pressure supporting. CA: Direct replacement, UNI.	CH-54A,B
96e	Servos FM: Leakage, wear. FN: Pressure supporting, force transmitting, force amplifying. CA: Improved part (primary servo improved strength by-pass valve). Improved associated part (servo valve input link). Strengthened part (additional link).	CH-54A,B
96f	Actuators FM: Leakage, wear. FN: Pressure supporting, force transmitting, force amplifying. CA: Direct replacement, UNI.	CH-54A,B
96G	Cylinders FM: Leakage, wear. FN: Pressure supporting, force transmitting,	CH-54A,B

TABLE XIV - Continued

Case/Item	Part Name / FM: Failure Mode(s) / FN: Function(s) / CA: Corrective Action(s)	Helicopter Type/Model/Series
96G (cont'd)	force amplifying. CA: Improved part (wheel brake boost cylinder).	
96h	Valves FM: Leakage. FN: Liquid switching, liquid constraining, pressure supporting, sealing. CA: Direct replacement,UNI.	CH-54A,B
96i	Seals FM: Leakage, wear. FN: Sealing. CA: Direct replacement,UNI. Improved part (dust boot).	CH-54A,B
96j	Filter FM: Clogged filter. FN: Filtering. CA: Direct replacement,UNI.	CH-54A,B
97	Cargo Hoist Limit Safety Switch FM: Wear, fatigue. FN: Electrical switching, limiting, electrical conducting. CA: Improved instructions to field personnel (precludes unwarranted adjustments or modifications),UU. Improved instructions to field personnel (stop continuing hoist reel-outs),UNI. Improved part (cargo stock release system).	CH-54A
98a	Housing Seal (O-Ring) FM: Leakage, yielding, elastic deformation. FN: Sealing, liquid constraining. CA: Improved part,TNI.	CH-54A,B
$98b_1$	Clutch Housing Bearing FM: Corrosion, wear. FN: Continuous rolling, motion constraining, supporting, friction reducing. CA: Changed vendor (deleted vendor),UU. Improved part (bearing SB125-2 from SB1125-1),UU.	CH-54A,B

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
$98b_2$	Clutch Housing Bearing Seal FM: Change in material property. FN: Sealing, contaminant constraining. CA: Direct replacement, UNI.	CH-54A,B
$98C_1$	Adapter Bearing FM: Corrosion, wear. FN: Continuous rolling, motion constraining, supporting, friction reducing. CA: Changed vendor (deleted vendor), UU. Improved part (bearing SB125-2 from SB1125-1), UU.	CH-54A,B
$98C_2$	Adapter Bearing Seal FM: Change in material property. FN: Sealing, contaminant constraining. CA: Direct replacement, UNI.	CH-54A,B
98d	Clutch Assembly FM: Leakage. FN: Clutching, coupling. CA: Improved part (bearing SB125-2 from SB1125-1), UU. Strengthened part (three pivot bolts), UU. Supplemental part (spacer), UU. Supplemental part (oil collector added), UU.	CH-54A,B
99a	Sensors (lateral) FM: Unknown. FN: Displacement indicating, signal transmitting, electrical transforming. CA: Not determined.	CH-54A,B
99b	Control Amplifier FM: Fatigue. FN: Electrical amplifying. CA: Not determined.	CH-54A,B
99c	Remote Stick FM: Unknown. FN: Motion transmitting, signal transmitting. CA: Not determined.	CH-54A,B

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
99d	Sensor (collective) FM: Unknown. FN: Displacement indicating, signal transmitting, electrical transforming. CA: Not determined.	CH-54A,B
99NA	Bulkhead Door Seal FM: Change in material property, bonding failure, leakage. FN: Sealing, protective covering. CA: Changed dimensions (made seal thicker .062" to .125"),UI. Improved instructions to field personnel (bonding seal material). Improved part (new door assy, seal, and adhesive),UU.	UH-1D
101	Cargo Hook Hole Bumper FM: Change in material property, bonding failure. FN: Protective covering, energy absorbing. CA: Change of material (silicone rubber to diester resistant material),UU. Improved part (rubber bumper on hook),UU. Eliminated part (removed bumper from airframe),UU.	UH-1D
103	Landing Gear Skid Shoe Bolt FM: Ductile rupture. FN: Removable fastening, attaching. CA: Changed method of attachment (locking feature added to nut).	UH-1D
104	Tail Rotor Cable FM: Wear, fatigue. FN: Force transmitting, linking, motion transmitting. CA: Changed dimensions of associated part (grommet enlarged),UU. Applied surface coating,TIR.[10]	UH-1D
107	Blackout Curtain Attachment Tape FM: Bonding failure. FN: Attaching, supporting. CA: Changed method of attachment (tape to studs),UU.	UH-1D

TABLE XIV - Continued	
Case/Item	**Part Name** — **Helicopter Type/Model/Series** **FM: Failure Mode(s)** **FN: Function(s)** **CA: Corrective Action(s)**
108	Soundproofing Blankets — UH-1D FM: Ductile rupture. FN: Sound absorbing, sound insulating, protective covering. CA: Change of material (changed to nylon cloth neoprene material MIL-C-20696), UI.
109a	Cargo-Hook Lock — UH-1D FM: Impact. FN: Attaching, motion constraining, latching, limiting. CA: Improved part (cargo hook), TIU. Changed mechanism of operation (new cargo suspension assembly eliminates need for shear pins), R.
109b	Shear Pin — UH-1D FM: Ductile rupture. FN: Force limiting. CA: Changed mechanism of operation (new cargo suspension assembly eliminates need for shear pins), R.
110a	Hydraulic Boost Cylinder Seals — UH-1D FM: Wear, leakage. FN: Sealing, liquid constraining. CA: Improved part (valve drive and vent, and seals), UU. Supplemental part (protective boot to keep out sand), UU. Eliminated part (back-up ring eliminated), UU.
110b	Hydraulic Cylinder — UH-1D FM: Wear, leakage. FN: Pressure supporting, force transmitting, force amplifying. CA: Improved part (valve drive and vent, and seals), UU. Supplemental part (protective boot to keep out sand), UU. Supplemental part (jam nut).
111a	Hydraulic Reservoir Boot — UH-1D FM: Change in material property. FN: Sealing, covering, contaminant constraining.

TABLE XIV - Continued

Case/Item	Part Name / FM: Failure Mode(s) / FN: Function(s) / CA: Corrective Action(s)	Helicopter Type/Model/Series
111a (cont'd)	CA: Direct replacement, UNI.	
112	Engine Air Induction Baffle FM: Fatigue. FN: Guiding, deflecting. CA: Reinforced part (added doubler on baffle), UU. Strengthened part (stiffened baffle), UU.	UH-1D
113a	Screen FM: Fatigue. FN: Filtering, protective covering. CA: Supplemental part (grommets added to isolate vibration), UI.	UH-1D
113b	Duct FM: Fatigue FN: Gas constraining, gas transferring, supporting, attaching. CA: Changed loading on part (changed brackets to reduce loading), UU. Changed dimensions of associated part (bracket dimensions increased), UU.	UH-1D
113c	Engine Flange FM: Fatigue. FN: Attaching, supporting. CA: Changed loading on part (changed brackets to reduce loading), UU. Changed dimensions of associated part (bracket dimensions increased), UU.	UH-1D
113d	Transmission Flange FM: Fatigue. FN: Attaching, supporting. CA: Changed loading on part (changed brackets to reduce loading), UU. Changed dimensions of associated part (bracket dimensions increased), UU.	UH-1D
114	Engine Compressor Blades FM: Erosion. FN: Force transmitting, pressure increasing.	UH-1D

TABLE XIV - Continued

Case/Item	Part Name / FM: Failure Mode(s) / FN: Function(s) / CA: Corrective Action(s)	Helicopter Type/Model/Series
114 (cont'd)	CA: Supplemental part (air inlet filter added), UU. Improved part (changed filters), R. Supplemental part (added particle separator with filter), UU.	
115	Stabilizer Bar Link Tube Bearings FM: Wear. FN: Oscillatory sliding, supporting, force transmitting, motion constraining, friction reducing, pivoting. CA: Changed vendor (deleted vendor), UU.	UH-1D
117	Pitch Link Rod End Bearing FM: Wear. FN: Oscillatory sliding, supporting, force transmitting, motion constraining, friction reducing, pivoting. CA: Improved part (changed bearing, purchased from another vendor), UU.	UH-1D
119a	Main Rotor Mast FM: Corrosion. FN: Torque transmitting, supporting, attaching, power transmitting. CA: Applied surface coating (MIL-C-11796 class 3 [RC-3]).	UH-1D
119b	Drag Brace Assembly FM: Corrosion. FN: Adjustable attaching, supporting. CA: Direct replacement, UNI.	UH-1D
119c	Round Nut FM: Corrosion. FN: Fastening, attaching. CA: Direct replacement, UNI.	UH-1D
119d	Drag Br ce Sleeve Bushing FM: Corrosion. FN: Load distributing. CA: Direct replacement, UNI.	UH-1D

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
119e	Hub Assembly FM: Corrosion. FN: Torque transmitting, supporting, force transmitting, attaching, pivoting. CA: Direct replacement, UNI.	UH-1D
119f	Bolt FM: Corrosion. FN: Fastening. CA: Applied surface coating (cadmium-plated bolt), UU.	UH-1D
119g	Retaining Ring FM: Corrosion. FN: Limiting, supporting, motion constraining. CA: Applied surface coating (cadmium-plated ring), UU.	UH-1D
119h	Helical Extension Spring FM: Corrosion. FN: Position restoring, force transmitting. CA: Direct replacement, UNI.	UH-1D
121a	Main Rotor Blade Leading Edge FM: Erosion, corrosion, buckling. FN: Protective covering, shielding. CA: **Change of material (stainless steel to cobalt)**, TIU. Applied surface coating (stainless steel, cobalt, or nickel), TI.	UH-1D
121b	Tail Rotor Blade Leading Edge FM: Erosion, corrosion. FN: Protective covering, shielding. CA: **Change of material (stainless steel to cobalt)**, TIU. Applied surface coating (stainless steel, cobalt, or nickel), TI.	UH-1D
122	Main Rotor Pitch Horn FM: Scoring. FN: Linking, force transmitting, attaching. CA: Repositioned associated part (turned bolt around), UU.	UH-1D

TABLE XIV - Continued	
Case/Item	Part Name — Helicopter Type/Model/Series FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)
124a	Drive Shaft Coupling — UH-1D FM: Wear, surface fatigue, leakage. FN: Coupling, torque transmitting, sliding, motion transmitting, motion constraining. CA: Changed lubricant type (204-040-755-3 to replace 204-040-755-1), UU. Improved instructions to field personnel (inspection and greasing of couplings), UU. Supplemental part (added elastomeric boot to retain lubricant and exclude contaminants).TIU. Change of material (new high temp steel for gear teeth),TIU. Eliminated part (auxiliary cooling fins not needed with other improvements), UU. Changed lubricant type (to replace 204-040-755-3), TI. Improved instructions to field personnel (lubrication inspection of main drive shaft and T/R drive shaft), UU.
124b	O-Ring — UH-1D FM: Leakage, ductile rupture. FN: Sealing, contaminant constraining. CA: Changed manufacturing procedure (to prevent cutting O-rings), UU. Supplemental part (added elastomeric boot to retain lubricant and exclude contaminants),TIU. Eliminated part (auxiliary cooling fins), UU.
125	Tail Rotor Hydraulic Boost Cylinder Seal — UH-1D FM: Ductile rupture, wear. FN: Sealing, liquid constraining. CA: Changed dimension (increased piston rod od to reduce cutting seals), UU.
126	Landing Gear Cross Tube Strap Rivets — UH-1D FM: Ductile rupture. FN: Permanent fastening, attaching. CA: Changed dimension (increased bearing strap width to increase edge distance to rivet), UU.

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
127	Cooling Fan Bearing FM: Wear. FN: Supporting, friction reducing, motion constraining, pivoting. CA: Improved instructions to field personnel (inspection, maintenance, and overhaul), UU. Eliminated part (removal of starter generator cooling fan on models with self-cooled starter generators installed), UU.	UH-1D
128a	Transmission Oil Plug FM: Wear. FN: Liquid constraining, covering, sealing. CA: Changed method of attachment (changed to screw plug from snap ring plug), UU.	UH-1D
128b	Snap Ring FM: Wear. FN: Limiting, supporting, motion constraining. CA: Changed method of attachment (changed to screw plug from snap ring plug), UU.	UH-1D
128c	O-Ring FM: Elastic deformation, leakage. FN: Sealing, liquid constraining. CA: Direct replacement, UNI.	UH-1D
130	Tail Rotor Sprocket Cover FM: Ductile rupture. FN: Protective covering. CA: Change of material (polycarbonate to Al. alloy 2024), UU.	UH-1D
132	Searchlight FM: Unknown. FN: Movable lighting, energy transforming. CA: Improved part (water resistant light), TI.	UH-1D
133	Voltage Regulator Terminals FM: Corrosion. FN: Attaching, electrical conducting.	UH-1D

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
133 (cont'd)	CA: Applied surface coating (anticorrosion treatments, platings),UU. Improved instructions to field personnel (for cleaning regulator base terminals), UU.	
134a	Engine Mount Tripod Tubes FM: Fatigue. FN: Supporting, attaching, force transmitting. CA: Improved quality control (reworked inspection and assembly fixtures),UU. Changed method of attachment (one leg pin jointed),R. Changed method of attachment (comparative welding techniques),T. [11]	UH-1D
134b	Support Bearing FM: Wear. FN: Motion constraining, friction reducing, oscillatory sliding, supporting. CA: Change of material (of bearing: bronze race to stainless steel race),UU. Changed vendor (deleted vendor),T.	UH-1D
136	Tail Rotor Installation Boot FM: Ductile rupture. FN: Sealing, covering, contaminant constraining. CA: Direct replacement,UNI. Improved part,TIR.	UH-1D
137	Main Rotor Hub Drag Brace Decal FM: Bonding failure. FN: Information attaching, information transmitting. CA: Changed adhesive material (alternate adhesive),UU. Changed manufacturing procedure (alternate method of manufacturing),UU. Change of material (bonded Al. decal to imprinted polyester tape),UU.	UH-1D
142a	Main Rotor Hub Assembly FM: Corrosion. FN: Torque transmitting, supporting, force transmitting, attaching, pivoting.	UH-1D

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
142a (cont'd)	CA: Applied surface coating (cadmium plated ID of yoke journals),UU. Supplemental part (O-rings and dust seals added),UU.	
142b	Grip Retention Acorn Nut FM: Galling, yielding. FN: Protective covering, supporting, attaching, limiting. CA: Supplemental part (Al. plates bonded to each end of 204-012-104-1 retention pin),UU.	UH-1D
143	Instrument Panel Pedestal Support Bracket FM: Fatigue. FN: Attaching, supporting. CA: Reinforced part (added doublers to failing bracket),UU. Reinforced part (additional doubler), UU.	UH-1D
144	Extension Light Bulbs FM: Fatigue. FN: Lighting, energy transferring. CA: Direct replacement,UNI.	UH-1D
145	Hinged Door Spring Stop FM: Ductile rupture, impact. FN: Sliding, latching, limiting. CA: Improved part (R. side only -1 to -3 part),UU. Direct replacement (on L. side),UNI.	UH-1D
146	Vertical Fin Access Door Hinge FM: Wear, fretting-wear. FN: Pivoting, supporting, motion constraining, attaching. CA: Changed method of attachment (of pin by crimping hinge half),UU. Change of material (MS 2001P4 Al. hinge to MS20257HC4 steel). Changed dimension (.090" dia. steel pin to .118" dia.).	UH-1D

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
147a	Tail Rotor Control Quill Sprocket FM: Wear. FN: Torque transmitting, constraining, linking, supporting. CA: Relaxed replacement criteria (deleted sprocket requirements).	UH-1D
147b	Chain FM: Wear. FN: Force transmitting, linking. CA: Improved instructions to field personnel, UU.	UH-1D
147c	Guard FM: Wear. FN: Limiting, covering. CA: Direct replacement, UNI.	UH-1D
149a	Engine Air Inlet Filter Seal FM: Bonding failure. FN: Sealing. CA: Changed adhesive material. Improved part.	UH-1D
149b	Engine Air Inlet Filter FM: Wear, fretting-corrosion. FN: Filtering, contaminant constraining. CA: Direct replacement, UNI.	UH-1D
149c	Engine Air Inlet Cowl FM: Wear, Fretting-corrosion. FN: Protective covering, streamlining. CA: Direct replacement, UNI.	UH-1D
152a	Hydraulic Reservoir Indicator Rod FM: Corrosion. FN: Position Indicating. CA: Direct replacement, UNI.	UH-1D
152b	Reservoir Body FM: Corrosion, leakage. FN: Attaching, covering, liquid constraining, sealing, liquid storing.	UH-1D

TABLE XIV - Continued	
Case/Item	**Part Name** **Helicopter Type/Model/Series** **FM: Failure Mode(s)** **FN: Function(s)** **CA: Corrective Action(s)**
152b (cont'd)	CA: Improved part (changed from pressurized to gravity feed), UU.
153	External Stores Jettison Lever Stop UH-1D FM: Yielding. FN: Limiting. CA: Changed dimensions (made stop thicker), UU. Changed manufacturing procedure (from riveted sheet metal to casting), UU.
154	Landing Light UH-1D FM: Unknown. FN: Movable lighting, energy transforming. CA: Improved part, TI.
156	Lift Center Beam UH-1D FM: Fatigue, fretting-fatigue. FN: Supporting, attaching. CA: Changed dimensions (increased thicknesses of beam webs), UU. Changed dimensions (fitting attachment made larger, more rivets), UU. Changed dimensions (cap angles made thicker and web gauge increased), UU.
157	Lift Link Fitting Rivets UH-1D FM: Fretting-wear, yielding. FN: Supporting, fastening, attaching. CA: Changed method of attachment (rivets and collars to high lock bolts), UU.
158a	Anticollision Light UH-1D FM: Unknown. FN: Position indicating, lighting, energy transforming. CA: Changed loading on part (increased shock resistance), UU. Supplemental part (added shock mounts), UU.
158b	Light Bulbs UH-1D FM: Fatigue. FN: Lighting, energy transforming.

TABLE XIV - Continued

Case/Item	Part Name / FM: Failure Mode(s) / FN: Function(s) / CA: Corrective Action(s)	Helicopter Type/Model/Series
158b (cont'd)	CA: Direct replacement, UNI.	
159	Stabilizer Bar Lever Bearing FM: Lubrication failure, corrosion, wear, surface fatigue, impact, brinelling. FN: Oscillatory rolling, supporting, friction reducing, motion constraining, pivoting. CA: Reinforced associated part (added material to reduce flexibility of lever), UU. Supplemental part (shims added between lever and stabilizer bar pivot bearing), UU. Improved part (larger bearing: new forging), R.	UH-1D
161	Transmission Fairing Seal FM: Bonding failure. FN: Sealing, protective covering. CA: Improved part (of seal), UU. Changed method of attachment (bonding to bonding and riveting), UU. Supplemental part (retainers added for riveting seal to cowl), UU.	UH-1D
162	Cargo Panel Door Hinges FM: Ductile rupture. FN: Pivoting, supporting, motion constraining, attaching. CA: Direct replacement (too costly to redesign: $27,000 / yr versus $122,000/ yr), UNI.	UH-1D
163	Rotor Blade Root Sockets FM: Fretting-corrosion, fretting-fatigue. FN: Attaching supporting, pivoting. CA: Applied surface treatment (shotpeened surfaces), UU. Relocated part (hole in part relocated 90 deg), T. Changed dimensions (increased wall thickness at hole), T. Applied surface treatment (shotpeen entire surface of adjacent lag damper arms), T. Changed dimension of associated part (increased length of plug), T. Applied surface coating on associated part (Dacron Teflon coating on plug), UU. Improved part (fwd and aft sockets), T.	CH-47

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
165a	Rotor Brake Plate FM: Scoring, yielding. FN: Energy absorbing, energy dissipating, motion reducing, sliding, torque transmitting. CA: Changed loading on part (brake springs changed from 5 lb to 9 lb),UU. Improved associated part (oil-impregnated brake lining),UU. Changed dimensions (counterbored brake plate),UU.	CH-47
165b	Potentiometer FM: Unknown. FN: Electrical conducting. CA: Direct replacement,UNI.	CH-47
166	Engine/Transmission Output Splines FM: Wear, imbalance. FN: Torque transmitting, power transmitting, force transmitting, sliding, motion constraining, coupling. CA: Added lubricant (to output splines; MIL-G-81322A grease),UU. Applied surface coating (silver-plated splines),T.	CH-47
167a	Fuel Line Check Valve FM: Leakage. FN: Liquid switching, liquid constraining, pressure supporting, sealing, motion limiting. CA: Improved part (new valves to replace check valves in main fuel tank and fuel feed manifold), UU.	CH-47
167b	Fuel System Centrifugal Pump Cover FM: Yielding, ductile rupture. FN: Liquid constraining, covering. CA: Improved part (new valves to replace check valves in main fuel tank and fuel feed manifold),UU.	CH-47

TABLE XIV - Continued	
Case/Item	**Part Name** **Helicopter Type/Model/Series** **FM: Failure Mode(s)** **FN: Function(s)** **CA: Corrective Action(s)**
167c	Bleed Actuator Lever Seals CH-47 FM: Elastic deformation. FN: Sealing, liquid constraining. CA: Improved part (new valves to replace check valves in main fuel tank and fuel feed manifold), UU.
167d	Fuel Quantity Indicator CH-47 FM: Electrical short. FN: Position sensing, signal transmitting. CA: Relocated associated part (reroute bonding jumper), UU. Supplemental part (added clamps to support jumper), UU. Improved instructions to field personnel (calibration chart to be supplied). Changed manufacturing procedure (factory calibrated for most dense fuel at -55 deg c).
168	N2 Potentiometer Slider Plate CH-47 FM: Wear, corrosion. FN: Electrical conducting, sliding. CA: Supplemental part (added jumper wire), UU. Improved part (new potentiometer), UU.
169a	N1 System CH-47 FM: Wear, seizure. FN: Electrical switching, limiting, electrical conducting. CA: Improved part (interim modifications), UU. Changed mechanism of operation (closed loop system), T. Improved instructions to field personnel (minimize mis-rigging of actuator), UU.
169b	N1 Power Lever Actuator CH-47 FM: Unknown. FN: Motion transmitting, force transmitting, energy transforming, torque transmitting. CA: Improved part (interim modifications), UU. Changed mechanism of operation (closed loop system), T. Improved instructions to field personnel (minimize mis-rigging of actuator), UU. Improved part (rigging holes in actuator), UU.

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
169c	Warning Light FM: Unknown. FN: Information transmitting, lighting, energy transforming. CA: Improved part (interim modification), UU. Changed mechanism of operation (closed loop system), T.	CH-47
169d	Control Box FM: Unknown. FN: Undefined. CA: Improved part (interim modifications), UU. Changed mechanism of operation (closed loop system), T.	CH-47
171b	Bearing FM: Corrosion, wear. FN: Motion constraining, friction reducing, oscillatory sliding, supporting. CA: Change of material (adapter: from Al. to steel). Supplemental part (added steel sleeve).	CH-47
171c	Bearing Adapter FM: Corrosion, wear. FN: Supporting, attaching, motion constraining. CA: Change of material (adapter: from Al. to steel).	CH-47
171d	Drag Strut FM: Fatigue. FN: Supporting. CA: Applied surface treatment (shotpeen fatigue area), Changed method of attachment (slip fit to press fit).	CH-47
172a	Crown Fairing Skins FM: Ductile rupture, fatigue. FN: Shielding, supporting, protective covering. CA: Change of material of associated part (cloth curtain to metal curtain), UU. Changed dimensions (increased thickness of metal skin). Improved part.	CH-47

TABLE XIV - Continued	
Case/Item	Part Name — Helicopter Type/Model/Series FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)
172b	Fairing Stiffeners — CH-47 FM: Fatigue, ductile rupture. FN: Shape constraining, reinforcing, supporting. CA: Change of material of associated part (cloth curtain to metal curtain), UU. Improved part.
175	Parking Brake Cable — CH-47 FM: Ductile rupture, seizure. FN: Force transmitting, linking. CA: Changed mechanism of operation (cable to rigid rod). Repositioned part (cable relocated for less load).
177a	Engine Quill Shaft — CH-47 FM: Galling. FN: Torque transmitting, sliding, limiting. CA: Supplemental part (added nylon snubber), TIU.
177b	Pinion Shaft — CH-47 FM: Galling. FN: Torque transmitting, sliding, limiting. CA: Supplemental part (added nylon snubber), TIU.
178a	Fuel Boost Pump — UH1D-H FM: Leakage. FN: Liquid pumping, liquid constraining, pressure increasing. CA: Changed mechanism of operation (air-driven pump replaced by electric fuel pump), UU.
178b	Fuel Pump Shaft — UH-1D,H FM: Ductile rupture, fatigue. FN: Force transmitting, torque transmitting. CA: Changed mechanism of operation (air-driven pump replaced by electric fuel pump), UU.
179	Hinged Cargo Panel Window — UH-1D FM: Impact, brittle fracture. FN: Protective covering, viewing, shielding, light transmitting. CA: Eliminated part (eliminated window in door), UU.

TABLE XIV - Continued	
Case/Item	**Part Name** **Helicopter Type/Model/Series** **FM: Failure Mode(s)** **FN: Function(s)** **CA: Corrective Action(s)**
180a	Tail Rotor Control Tube UH-1D FM: Yielding, galling. FN: Force transmitting, sliding. CA: Added locking feature (in addition to cotter pin, nylon insert in nut), UU. Improved instructions to field personnel (specified lower tightening torque), UU. Changed loading on part (reduced tightening torque), UU.
180b	Tail Rotor Control Tube Nut UH-1D FM: Yielding, galling. FN: Removable fastening, attaching. CA: Added locking feature (in addition to cotter pin, nylon insert in nut), UU. Improved instructions to field personnel (specified lower tightening torque), UU. Changed loading on part (reduced tightening torque), UU.
182	5th Transmission Mount Support Beam UH-1D FM: Fatigue. FN: Attaching, supporting. CA: Improved part (improve beam assy for 5th transmission mount), UI.
183a	Elevator Control Idler Bearing UH-1D FM: Wear. FN: Oscillatory rolling, supporting, friction reducing, motion constraining, pivoting, force transmitting. CA: Changed adhesive material (improved bonding of Teflon fabric), UU.
183b	Clevis to Idler Bolt UH-1D FM: Wear. FN: Removable fastening, supporting, attaching. CA: Direct replacement, UNI.
184a	Bearing UH-1D FM: Seizure. FN: Oscillatory rolling, supporting, friction reducing,

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
184a (cont'd)	motion constraining, pivoting, force transmitting. CA: Changed mechanism of operation (ball bearings to spherical bearing), UU.	
184b	Bearing Seal FM: Leakage. FN: Sealing. CA: Changed mechanism of operation (ball bearings to spherical bearing), UU.	UH-1D
185	Magnetic Brake FM: Corrosion, seizure. FN: Variable Position Maintaining. CA: Revised procurement specifications, UU.	UH-1C, D
188a	Wing Shaft Splines FM: Fatigue, fretting-corrosion. FN: Attaching, torque transmitting. CA: Applied surface treatment (shotpeened spline area), UU. Changed dimensions (added fillet to spline teeth roots), UU. Applied surface coating (application of corrosion preventative), UU. Changed loading on part (assigned tightening torque), UU. Added adhesive (used metal-set A-4 to splines), UU. Changed manufacturing procedure (spline tolerances relaxed), UU. Improved part (stabilizer bar damper wing shaft and mating lever), R.	UH-1D
188b	Stabilizer Bar Dampers FM: Leakage, wear. FN: Motion damping, energy absorbing, energy dissipating, motion reducing, stabilizing. CA: Direct replacement, UNI. Improved part (stabilizer bar damper wing shaft and mating lever), R.	UH-1D
189	Seat Armor Rubber Protective Strip FM: Bonding failure. FN: Protective covering, force distributing. CA: Changed adhesive material (to bond and repair	UH-1D

TABLE XIV - Continued	
Case/Item	**Part Name** **Helicopter Type/Model/Series** **FM: Failure Mode(s)** **FN: Function(s)** **CA: Corrective Action(s)**
189 (cont'd)	loose strip), UU.
190a	Transmission Mount UH-1D FM: Wear, change in material property, bonding failure. FN: Attaching, supporting, motion constraining. CA: Direct replacement (no action: attributed to maintenance), UNI.
190b	Transmission Mount Boot UH-1D FM: Ductile rupture. FN: Sealing, covering, contaminant constraining. CA: Direct replacement (no action: attributed tc maintenance), UNI.
190c	5th Mount UH-1D FM: Wear, change in material property, bonding failure. FN: Attaching, supporting, motion constraining. CA: Direct replacement (no action. attributed to maintenance), UNI.
192	Cargo Floor UH-1D FM: Impact, bonding failure. FN: Supporting, attaching. CA: Direct replacement, UNI.
200	Upper Link Assembly CH-54 FM: Wear, impact. FN: Linking, supporting, force transmitting. CA: Direct replacement (considered normal wear), UNI.
201	Main Rotor Damper Bearing CH-54 FM: Wear. FN: Oscillatory sliding, supporting, force transmitting, motion constraining, friction reducing, pivoting. CA: Improved quality control (better bonding of Teflon on spherical bearing), UU.

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
202	Push-Pull Control Collective Bias FM: Seizure. FN: Force transmitting, linking. CA: Direct replacement (collective bias control cable only),UNI. Relocated part (collective bias synchronizer). More easily replaceable. Changed method of attachment (two mounting brackets instead of common bracket).	CH-54
203	APP Support, Rod End Bearing FM: Wear. FN: Motion constraining, friction reducing, oscillatory sliding, supporting. CA: Direct replacement,UNI. Change of material (Teflon lined bearing). Improved part (forward mount bracket).	CH-54
206	Main Rotor Servo Cylinder Pressure Switch FM: Corrosion, leakage. FN: Electrical switching, pressure supporting, pressure sensing, electrical conducting. CA: Direct replacement (pressure switch),UNI. Improved part.	CH-54
207a	2nd-Stage Hydraulic Manifold Seal FM: Leakage. FN: Sealing, liquid constraining. CA: Direct replacement,UNI. Improved part.	CH-54
207b	Shut-Off Solenoid FM: Unknown. FN: Liquid switching, energy transforming, sealing. CA: Direct replacement,UNI. Improved part.	CH-54
208a	Free Turbine Case Assy. FM: Ductile rupture, fatigue. FN: Attaching, supporting, gas constraining, sealing.	CH-54

TABLE XIV - Continued

Case/Item	Part Name / FM: Failure Mode(s) / FN: Function(s) / CA: Corrective Action(s)	Helicopter Type/Model/Series
208a (cont'd)	CA: Repaired part (welded cracked turbine case assy), UNI.	
208b	Turbine Exhaust Duct FM: Fatigue, stress rupture. FN: Attaching, supporting, gas constraining, deflecting, shielding. CA: Repaired part (welded cracked turbine exhaust duct), UNI. Direct replacement (exhaust duct), UNI. Improved instructions to field personnel (to detect cracks), UU.	CH-54
209	Aft Cargo Light FM: Fatigue, wear. FN: Movable lighting, energy transforming. CA: Direct replacement, UNI.	CH-54
210	Oil Strainer Cap FM: Ductile rupture, fatigue, yielding. FN: Removable covering. CA: Changed dimensions (made part thicker), UU.	CH-54
211	JFTD12A-5A Engine FM: Leakage, ductile rupture. FN: Energy transforming. CA: Direct replacement (replaced entire engine in some cases), UNI. Repaired part (repaired some engines on helicopters), UNI.	CH-54
212a	Packing Preform FM: Yielding, change in material property, leakage. FN: Sealing, liquid constraining. CA: Direct replacement, UNI.	CH-54
213	Starter Dropout Relay FM: Unknown. FN: Electrical conducting, electrical switching, sensing. CA: Improved quality control. Direct replacement, UNI.	CH-54

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
214	Anticollision Light FM: Wear, impact-fatigue. FN: Position indicating, lighting, energy transforming. CA: Direct replacement (of light assy),UNI.	CH-54
215	Engine Fuel Pressure Switch FM: Corrosion. FN: Electrical switching, pressure supporting, pressure sensing, electrical conducting. CA: Improved part. Relocated part (to reduce contamination from refueling manifold). Changed loading on part (eliminated exposure to external refueling pressure).	CH-54
216a	HF Antenna "T" Fitting FM: Ductile rupture, fatigue. FN: Supporting, attaching. CA: Eliminated part (removed antenna),UU. Improved part,R. Changed mechanism of operation (utilized LF/ADF antenna for HF operation).	CH-54
216b	Rubber Boot FM: Creep, change in material properties. FN: Covering, sealing, contaminant constraining. CA: Eliminated part (removed antenna). Improved part,R. Changed mechanism of operation (utilized LF/ADF antenna for HF operation).	CH-54
218	CAN, Altitude Control (EPR) Cover FM: Fatigue, ductile rupture. FN: Covering, sealing, contaminant constraining. CA: Repaired part (cover for EPR),UNI.	CH-54
219	Tail Rotor Blade Tip Cap FM: Ductile rupture, fatigue. FN: Streamlining, protective covering. CA: Direct replacement (TR tip cap),UNI.	CH-54

TABLE XIV - Continued

Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
220	Power Boost Cylinder Seal FM: Leakage. FN: Sealing, liquid constraining. CA: Direct replacement (cylinder assy and/or just seal), UNI.	CH-54
222a	Utility Pump FM: Wear. FN: Pumping, pressure increasing, liquid transferring, pressure supporting. CA: Direct replacement, UNI. Improved instructions to field personnel (bleeding hydraulic system), UU.	CH-54
222b	Packing Preform FM: Change of material property, leakage. FN: Sealing, liquid constraining. CA: Direct replacement, UNI.	CH-54
223	Pitch Change Rod End Bearings FM: Wear, scoring, impact. FN: Oscillatory sliding, supporting, force transmitting, motion constraining, friction reducing, pivoting. CA: Change of material (from fiberglide to KAHR 97613), UU.	CH-54
224	Main Rotor Blade Attachment Bolts FM: Corrosion. FN: Removable fastening, supporting, attaching. CA: Direct replacement, UNI. Changed loading on part (improved load sharing design). Applied surface coating (post plate chromate treatment). Improved instructions to field personnel (inspect for corrosion), UU. Applied surface coating to supplemental part (silver-plated washers).	CH-54
225	Sleeve/Spindle Seal FM: Leakage, wear. FN: Sealing, liquid constraining.	CH-54

TABLE XIV - Continued		
Case/Item	Part Name FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)	Helicopter Type/Model/Series
225 (cont'd)	CA: Changed lubricant type (to MIL-L-21260, Type 1, Grade 50). Improved part (sleeve and spindle seal). Direct replacement (entire sleeve/spindle assy.), UNI.	
226	Main Gearbox Oil Pressure Switch FM: Corrosion, seizure. FN: Electrical switching, pressure supporting, pressure sensing, electrical conducting. CA: Improved part (switch assembly). Changed loading on part (added vibration isolator). Direct replacement, UNI.	CH-54
227	Core Flex Shaft FM: Wear, leakage. FN: Flexible torque transmitting, flexible motion transmitting. CA: Changed method of lubrication (flex cable: 4 test kits only). Direct replacement, UNI.	CH-54
228a	Cargo Hoist Decoupler FM: Ductile rupture, leakage, fatigue. FN: Damping, energy absorbing, energy dissipating, force sensing, disconnecting. CA: Direct replacement, UNI. Changed mechanism of operation (fluid spring to elastomeric spring). Changed loading on part (increased damping force).	CH-54
228b	Retaining Ring FM: Ductile rupture. FN: Limiting, supporting. CA: Changed mechanism of operation (fluid spring to elastomeric spring).	CH-54
230	Rotor Brake Pressure Switch Diaphragm FM: Ductile rupture. FN: Liquid constraining, pressure supporting, pressure sensing, motion transmitting. CA: Direct replacement, UNI. Relocated part (to reduce	CH-54

TABLE XIV - Continued	
Case/Item	**Part Name** **Helicopter Type/Model/Series** **FM: Failure Mode(s)** **FN: Function(s)** **CA: Corrective Action(s)**
230 (cont'd)	vibration on pressure switch).
244a	Cargo Hook Bumper Assy CH-54 FM: Wear. FN: Sealing, protective covering, energy absorbing. CA: Supplemental part (molded rubber tip and scraper ring). Improved part (Teflon bearing).
244b	Slip Ring CH-54 FM: Corrosion. FN: Sliding, electrical conducting. CA: Improved part (improved sealing and electrical contacts).
245a	Free Wheel Gear Clutch Roller Race CH-54 FM: Wear. FN: Supporting, torque transmitting, clutching. CA: Applied surface coating (tungsten-carbide flame-plated coating to reduce wear). Changed method of lubrication (pressurized lubrication with dam).
246	Main Rotor Droop Restrainer CH-54 FM: Unknown. FN: Limiting CA: Changed dimension of associated part (bolt 5/8" to 3/4" dia.). Changed dimensions (bearings and lock). Eliminated part (bushing).
247a	Control Rod Bearing Sleeve CH-54 FM: Wear. FN: Oscillatory sliding, supporting, adjustable attaching, force transmitting, friction reducing, motion constraining. CA: Applied surface coating (chrome plated).
247b	Thrust Washer CH-54 FM: Wear. FN: Force transmitting, supporting, friction reducing, sliding, motion constraining.

TABLE XIV - Continued	
Case/Item	**Part Name** — **Helicopter Type/Model/Series** **FM: Failure Mode(s)** **FN: Function(s)** **CA: Corrective Action(s)**
247b (cont'd)	CA: Applied surface coating (nickel sulfamate plated).
248a	Tail Rotor Blade Bolts — CH-54 FM: Corrosion. FN: Removable fastening, supporting, attaching. CA: Improved instructions to field personnel (inspect for corrosion),UU. Changed loading on part (improved load sharing design). Applied surface coating (post plate chromate treatment).
248b	Washers — CH-54 FM: Corrosion. FN: Force distributing, supporting. CA: Improved instructions to field personnel (inspect for corrosion),UU. Applied surface coating (silver plated).
250	Cargo Hoist Assembly Cable — CH-54 FM: None indicated. FN: Supporting, force transmitting. CA: Changed dimensions (decreased wire size in rope from .058" to .032"). Changed dimension of associated part (decoupler support plate). Strengthened part (breaking strength increased from 58,000 lb to 75,000 lb).
251a	Cabin Floor Panels — CH-47 FM: Corrosion. FN: Supporting, attaching. CA: Change of material (magnesium to aluminum),R.
251b	Tiedown Beams — CH-47 FM: Corrosion. FN: Supporting, attaching. CA: Change of material (magnesium to aluminum),R.
252	Main Rotor Blade Retention Bolts — UH-1 FM: Corrosion, wear, fretting-corrosion. FN: Removable fastening, supporting, attaching.

TABLE XIV - Continued	
Case/Item	**Part Name** / **Helicopter Type/Model/Series** **FM: Failure Mode(s)** **FN: Function(s)** **CA: Corrective Action(s)**
252 (cont'd)	CA: Applied surface coating (changed from chrome-cadmium to tung. carbide). Change of material (of coating: chrome-cadmium to tung. carbide).
253a	Irreversible Valve O-Rings — UH-1D FM: Fatigue, elastic deformation, leakage. FN: Sealing, liquid constraining. CA: Changed mechanism of operation (of O-ring to T-seal).
253b	Cylinder — UH-1D FM: Corrosion. FN: Liquid constraining, sliding, guiding. CA: Changed mechanism of operation (venting of spring cavity changed).
253c	Piston — UH-1D FM: Wear. FN: Force transmitting, sliding, liquid constraining, pumping, liquid transferring. CA: Changed dimension (increased piston length to reduce wear).
253d	Flow Bolts — UH-1D FM: Yielding. FN: Removable fastening, liquid transferring, liquid constraining. CA: Change of material (Al. alloy to cadmium-plated steel).
256	AFCS Pedal Switches — CH-54 FM: Unknown. FN: Electrical switching, force sensing, electrical conducting. CA: Relocated part (moved switches). Changed mechanism of operation of associated part (force link to fixed rod assy).
258	Fwd and Aft Rotor Shafts — CH-47 FM: Fatigue. FN: Torque transmitting, supporting, attaching,

TABLE XIV - Continued

Case/Item	Part Name / FM: Failure Mode(s) / FN: Function(s) / CA: Corrective Action(s)	Helicopter Type/Model/Series
258 (cont'd)	power transmitting. CA: Applied surface treatment (shotpeening to increase fatigue life),UU.	
259a	Fuel Sump Filter FM: Clogged filter. FN: Filtering, contaminant constraining. CA: Direct replacement,UNI. Improved part,T. More easily replaceable.	UH-1D,H
259b	Breakaway valves FM: Unknown. FN: Attaching, sealing, switching, disconnecting, liquid constraining. CA: Changed mechanism of operation,TI.	UH-1D,H
260	Cabin Vent Fan Vanes FM: Fatigue, ductile rupture. FN: Pressure increasing, guiding. CA: Changed vendor (or deleted vendor of vent fan),T.	AH-1G
261	Swashplate Drive Link FM: Fretting-fatigue, fatigue. FN: Linking, supporting, force transmitting. CA: Applied surface coating (to reduce fretting using Narmco 250 fretting inhibitor),TI.	AH-1G
262	Tail Rotor Hub Grips FM: Corrosion. FN: Attaching, supporting, force transmitting, torque transmitting. CA: Added sealant (MIL-S-8802, Class A-2: Proseal 890), T.	UH/AH-1
263	Rescue Hoist Cable FM: Ductile rupture, fatigue. FN: Supporting, force transmitting. CA: Changed lubricant type (grease to dry Teflon lube). Improved instructions to field personnel for associated part (more frequent overhaul of parts).	UH-1F,P,N

TABLE XIV - Continued	
Case/Item	Part Name Helicopter Type/Model/Series FM: Failure Mode(s) FN: Function(s) CA: Corrective Action(s)

[1] UU - Used, unknown results.
[2] UNI - Used, no improvement indicated.
[3] TI - Tested, with improvement indicated.
[4] UI - Used, with improvement indicated.
[5] R - Rejected corrective proposal.
[6] TIN - Tested, with improvement indicated, but not used.
[7] TIU - Tested, with improvement indicated, used.
[8] N - Not used as a corrective measure.
[9] TNI - Tested, no improvement indicated.
[10] TIR - Tested with improvement, rejected.
[11] T - Tested corrective proposal is only information available.

TABLE XV. SECTION THROUGH FAILURE-EXPERIENCE MATRIX REVEALING IDENTIFICATION OF CASE HISTORIES FOR WHICH THE "CHANGE OF MATERIAL" CORRECTIVE ACTION WAS PROPOSED

Functions / Failure Modes	Energy Absorbing	Sound Absorbing	Electrical Amplifying	Force Amplifying
1. Wear				
2. Ductile Rupture		108		
3. Fatigue				
4. Leakage				16b,16c
5. Yielding				
6. Impact				
7. Corrosion				
8. Bonding Failure	101			
9. Seizure				
10. Surface Fatigue				
11. Galling				
12. Scoring				
13. Material Prop. Change	101			
14. Erosion				
15. Fretting-Fatigue				
16. Elastic Deformation				
17. Imbalance				
18. Fretting-Corrosion				
19. Brittle Fracture				
20. Stress Rupture				
21. Fretting-Wear				
22. Lubrication Failure				
23. Improper Dimension				
24. Delamination				
25. Buckling				
26. Impact-Fatigue				
27. Clogged Filter				
28. Electrical				
29. Creep				
30. Brinelling				
31. Corrosion Fatigue				
32. Elec.-Ch. Overheating				
33. Radiation Damage				
34. Thermal Relaxation				
35. Thermal Shock				
36. Combined Creep/Fatigue				
37. Stress Corrosion				
38. Corrosion-Wear				
39. Spalling				
40. Creep-Buckling				

TABLE XV - Continued					
	Attaching	Adjustable Attaching	Information Attaching	Clutching	Electrical Conducting
1.	22d,63a,72, 146,171c,252				
2.	16g,38b,44g, 63a,63b				44e
3.	16g,22d,38b, 44g,63a,63b,84				44e
4.	16g				
5.	63a,63b				
6.	63a,63b				
7.	70,251a,251b, 252				
8.			137		
9.					
10.					
11.					
12.					
13.					
14.					
15.					
16.					
17.					
18.	252				
19.					
20.					
21.	63b,146				
22.					
23.					
24.					
25.					
26.					
27.					
28.					
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TABLE XV - Continued				
	Constraining	Contaminant Constraining	Gas Constraining	Liquid Constraining
1.		60b,94a		8d,16d,16e
2.		60b,94a	44a,44c	16d,16e,44b,96a
3.			44a,44c	44b,96a
4.		94a		16d,16e,16f,96a
5.		94a		253d
6.				
7.				
8.				
9.				
10.				
11.				
12.				
13.		60b		
14.				
15.				
16.				
17.				
18.				
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	TABLE XV - Continued				
	Motion Constraining	Shape Constraining	Coupling	Flexible Coupling	Covering
1.	3d,22d,29a,29b, 32b,51a,54b,54f, 54g,124a,134b,146, 171b,171c,203,223		124a		
2.		172b			
3.	3d,22d	172b			
4.	124a		124a		
5.					
6.	223				
7.	171b				
8.	51a				
9.					
10.	54b,54f,54g,124a		124a		
11.	3d				
12.	223				
13.					
14.					
15.					
16.					
17.					
18.					
19.					
20.					
21.	146				
22.					
23.					
24.					
25.					
26.					
27.					
28.					
29.					
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TABLE XV - Continued

	Protective Covering	Removable Covering	Damping	Motion Damping	Deflecting	Disconnecting
1.	47e					
2.	44d,65a,65b, 108,130, 172a					
3.	44d,65a,65b, 172a					
4.						
5.	65a					
6.	43a					
7.	121a,121b					
8.	82b					
9.						
10.						
11.	65a,65b					
12.	2a,43a,64					
13.	101					
14.	43a,82b,121a, 121b					
15.						
16.						
17.						
18.						
19.						
20.	2a,43a,64					
21.						
22.						
23.						
24.	64,101					
25.	121a					
26.						
27.						
28.						
29.						
30.						
31.						
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TABLE XV - Continued					
	Energy Dissipating	Electrical Distributing	Force Distributing	Load Distributing	Fastening
1.					
2.		44e			
3.		44e			
4.					
5.			11b		
6.					
7.					
8.					
9.					
10.					
11.					
12.					
13.					
14.					
15.					
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TABLE XV - Continued						
	Permanent Fastening	Removable Fastening	Filtering	Guiding	Gas Guiding	Pressure Increasing
1.		63a,252	3d			
2.	63b	63a		41c,44c	44a	41c
3.	63b	63a	3d	41c,44c	44a	41c
4.						
5.	63b	63a,253d				
6.	63b	63a				
7.		252				
8.						
9.						
10.						
11.			3d			
12.						
13.						
14.						
15.						
16.						
17.						
18.		252				
19.						
20.						
21.	63b					
22.						
23.						
24.						
25.						
26.						
27.						
28.						
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TABLE XV - Continued					
	Displacement Indicating	Information Indicating	Position Indicating	Pressure Indicating	Electrical Insulating
1.					
2.					
3.					
4.					
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TABLE XV - Continued						
	Sound Insulating	Latching	Temporary Latching	Lighting	Movable Lighting	Limiting
1.						
2.	108					48c
3.						48c
4.						
5.						
6.						48c
7.						
8.						
9.						
10.						
11.						
12.						
13.						
14.						
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16.						
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TABLE XV - Continued						
	Electrical Limiting	Motion Limiting	Pressure Limiting	Torque Limiting	Linking	Force Maintaining
1.						
2.		44e				
3.		44e				
4.						
5.						
6.						
7.						
8.						
9.						
10.						
11.						
12.						
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TABLE XV - Continued						
	Variable Position Maintaining	Partitioning	Pivoting	Pumping	Liquid Pumping	Electrical Reducing
1.			22d,29b, 146,223			
2.						
3.			22d			
4.						
5.						
6.			223			
7.						
8.						
9.						
10.						
11.						
12.			223			
13.						
14.						
15.						
16.						
17.						
18.						
19.						
20.						
21.			146			
22.						
23.						
24.						
25.						
26.						
27.						
28.						
29.						
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TABLE XV - Continued						
	Friction Reducing	Motion Reducing	Reinforcing	Position Restoring	Rolling	Continuous Rolling
1.	29a,29b, 51a,54b, 54f,54g, 134b,171b, 203,223					54f,54g
2.			172b			
3.			172b			
4.						
5.						
6.	223					
7.	171b					
8.	51a					
9.						
10.	54b,54f, 54g					54f,54g
11.						
12.	223					
13.						
14.						
15.						
16.						
17.						
18.						
19.						
20.						
21.						
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TABLE XV - Continued						
	Oscillatory Rolling	Sealing	Sensing	Force Sensing	Position Sensing	Pressure Sensing
1.	29a	8d,60b, 94a				
2.		16g,38b, 60b,94a				
3.		16g,38b				
4.		16f,16g, 94a				
5.		94a				
6.						
7.						
8.						
9.						
10.						
11.						
12.						
13.		60b				
14.						
15.						
16.						
17.						
18.						
19.						
20.						
21.						
22.						
23.						
24.						
25.						
26.						
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TABLE XV - Continued					
	Shielding	Sliding	Oscillatory Sliding	Spacing	Flexible Spacing
1.		47e,124a	15f,29b,32b,51a,54b, 76b,76c,76e,76f,76g, 76h,76k,76L,91c, 134b,171b,203,223		
2.	65a,65b,172a				
3.	65a,65b,172a				
4.		124a	76b,76c,76e,76f,76g, 76h,76k,76L		
5.	65a				
6.	43a		223		
7.	121a,121b		171b		
8.			51a		
9.			76b,76c,76e,76f,76g, 76h,76k,76L		
10.		124a	54b		
11.	65a,65b		76b,76c,76e,76f, 76g,76h,76k,76L		
12.	2a,43a,64		223		
13.					
14.	43a,121a,121b				
15.					
16.					
17.					
18.					
19.					
20.	2a,43a,64				
21.					
22.					
23.					
24.	64				
25.	121a				
26.					
27.					
28.					
29.					
30.					
31.					
32.					
33.					
34.					
35.					
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TABLE XV - Continued					
	Stabilizing	Energy Storing	Liquid Storing	Streamlin'g	Supporting
1.					3d,22d,29a,29b,32b,51a, 54b,54f,54g,72,76b,76c, 76e,76f,76g,76h,76k,76L, 91c,134b,146,171b,171c, 203,223,252
2.				65b	7,16g,38b,44f,48c,172a, 172b
3.				65b	3d,7,16g,22d,38b,44f,44g, 48c,54f,54g,84,172a,172b
4.		55			16g,76b,76c,76e,76f, 76g,76h,76k,76L
5.					7
6.					7,48c,223
7.					7,70,171b,251a,251b,252
8.				82b	7,51a
9.					76b,76c,76e,76f,76g, 76h,76k,76L
10.					54b
11.				65b	3d,76b,76c,76e,76f,76g, 76h,76k,76L
12.					223
13.					
14.				82b	7
15.					
16.					
17.					
18.					252
19.					
20.					
21.					146
22.					
23.					
24.					7
25.					
26.					
27.					
28.					
29.					
30.					
31.					
32.		55			
33.					
34.					
35.					
36.					
37.					
38.					
39.					
40.					

	Flexible Supporting	Pressure Supporting	Temporary Supporting	Switching	Electrical Switching
1.		16d,16e			
2.		16d,163,96a			44e
3.		96a			44e
4.		16b,16c,16d, 16e,16f,96a			
5.					
6.					
7.					
8.					
9.					
10.					
11.					
12.					
13.					
14.					
15.					
16.					
17.					
18.					
19.					
20.					
21.					
22.					
23.					
24.					
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26.					
27.					
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TABLE XV - Continued					
	Gas Switching	Liquid Switching	Gas Transferring	Liquid Transferring	Electrical Transforming
1.				16d,16e	
2.			44a,44c	16d,16e,96a	
3.			44a,44c	96a	
4.				16d,16e,96a	
5.				253d	
6.					
7.					
8.					
9.					
10.					
11.					
12.					
13.					
14.					
15.					
16.					
17.					
18.					
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TABLE XV - Continued

	Energy Transforming	Pressure-to-Torque Transforming	Aerodynamic Force Transmitting	Electrical Transmitting	Flexible Motion Transmitting
1.					
2.	7		7		
3.	7		7		
4.	55				
5.	7		7		
6.	7		7		
7.	7		7		
8.	7		7		
9.					
10.					
11.					
12.					
13.					
14.	7		7		
15.					
16.					
17.					
18.					
19.					
20.					
21.					
22.					
23.					
24.	7		7		
25.					
26.					
27.					
28.					
29.					
30.					
31.					
32.	55				
33.					
34.					
35.					
36.					
37.					
38.					
39.					
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TABLE XV - Continued					
	Flexible Torque Transmitting	Force Transmitting	Information Transmitting	Light Transmitting	Motion Transmitting
1.		29b,32b,72, 223			124a
2.					
3.					
4.		16b,16c			124a
5.					
6.		223			
7.					
8.			137		
9.					
10.					124a
11.					
12.		223		2a	
13.					
14.					
15.					
16.					
17.					
18.					
19.					
20.				2a	
21.					
22.					
23.					
24.					
25.					
26.					
27.					
28.					
29.					
30.					
31.					
32.					
33.					
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TABLE XV - Continued				
	Power Transmitting	Signal Transmitting	Torque Transmitting	Viewing
1.			124a	
2.				
3.				
4.			124a	
5.				
6.				43a
7.				
8.				
9.				
10.			124a	
11.				
12.				2a,43a,64
13.				
14.				43a
15.				
16.				
17.				
18.				
19.				
20.				2a,43a,64
21.				
22.				
23.				
24.				64
25.				
26.				
27.				
28.				
29.				
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31.				
32.				
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LIST OF SYMBOLS

d_{abr}	depth of abrasive wear, in.
d_w	depth of adhesive wear, in.
f_θ	normal operating frequency of angular motion, cpm
k_{abr}	experimental abrasive wear constant, in.^{2}/lb
k_w	experimental adhesive wear constant, in.^{2}/lb
L_1, L_2	life at a specific stressor level, cycles or hr
L_{hi}	life at a high stressor value, cycles or hr
L_{op}	life at operating stressor level, cycles or hr
L_P	time to failure with the load P fluctuating at its standard reference frequency, in wear test series in which the operational load amplitude is the stressor, hr
L_{Ps}	time to failure under static load P, in wear test series in which the operational load amplitude is the stressor, hr
L_s	distance of sliding, ft or in.
L_θ	time to failure with load P fluctuating at its standard reference frequency, in wear test with operational frequency of angular motion as the stressor, hr
$L_{\theta s}$	time to failure under static load P, in wear test series in which the operational frequency of angular motion is the stressor, hr
N	maximum number of passes for zero wear
P	normal operating amplitude of axial load, lb
p_m	mean nominal contact pressure, psi
S_1, S_2	stressor levels

LIST OF SYMBOLS - Continued

S_{hi}	a high value of the stressor
S_{op}	normal operating stressor level
t_1, t_2, t_3	time of operation at stressor level 1, 2, etc., hr
α	fraction of life at which component is operated at stressor level S_1
β	fraction of life at which component is operated at stressor level S_2
γ_r	experimental constant
σ_{yp}	yield point strength of the material, psi
τ_{max}	maximum shearing stress, psi
τ_{yp}	shear yield point of the material, psi